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ARCTIC SNOWMOBILE DESIGN STUDY

Final Report

Prepared for the

Transportation Development Centre

Transport Canada

by: Peter J. Poole, Ph.D.

for: Nunasi Corporation

July 1984

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

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17. Abstract

The report assesses the feasibility of producing an Arctic utility snowmobile combining off-the-shelf components with others manufactured with labour intensive, rather than capital intensive, methods. This snowmobile would be marketed in kit form, with possibility of local assembly operations in northern communities.

Innovative features with Arctic utility potential have been incorporated in the design, such as a larger cargo area, towing capability for a one ton komatik, and short term floatation in case of ice breakthrough. The kit form allows for addition and substitution of options to cater to cater to the various needs of users.

The report illustrates a number of design possibilities and evaluates the cost of production of kits. For a mid-sized vehicle this was found to be competitive with the cost of snowmobiles currently sold in the north. Furthermore, there is scope for transferring most of the labour's cost of production northward, approximately 35% of the total cost.

The report concludes that the project is feasible and recommends proceeding to the prototype phase.

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17. Résumé

Ce rapport étudie la possibilité de production d'une motoneige utilitaire arctique qui combinerait des pièces disponibles sur le marché avec des composantes fabriquées selon des méthodes artisanales plûtot qu'industrielles. Cette motoneige serait vendue soit en pièces détachées, soit après assemblage par un atelier dans le Nord.

Diverses innovations sont introduite dans ce concept, chacune ayant une destination utilitaire pour le Nord, soit: volume de bagage accru, possibilité de tirer un komatik d'une tonne et, en cas de rupture de la glace, temps de flotation adéquat. La vente en pièces detachées permettrait les additions et substitutions d'options suivant les besoins de l'utilisateur.

Ce rapport illustre quelques variantes du concept et evalue le coût de la trousse de construction. Pour une motoneige moyenne, le coût se compare très favorablement à celui d'un modèle commercial, livré dans le Grand Nord. De plus, il serait possible de fabriquer les composantes spécifiques au modèle dans le Nord, d'ou transfert d'environ 35% du cout total vers l'économie autochtone.

Le rapport conclut à la faisabilité du concept et recommende la construction d'un prototype.

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1. INTRODUCTION

1.1. Objective

To assess the feasibility of producing a utility snowmobile suitable for use in northern Canada and marketable in a kit form. A positive assessment will be accompanied by drawings which can be used as the basis for the construction of a prototype.

1.2. Historical Background

A previous study traced the progress in snowmobile design over the last thirty years (1) and Appendix A. The advances that have been achieved were dominated by demands to improve the recreational performance of snowmobiles. While this undoubtedly yielded incidental benefits for utility performance, it was rarely the direct objective of design research and development during this period. In fact, the principal utility machine still in use, the Bombardier Alpine, is essentially the same machine that was tested by the Canadian Armed Forces in 1963.

Not only has the design effort been exclusively devoted to improving the recreational capacities of snowmobiles, but these also have become gradually more limited as sport snowmobiling became increasingly confined to movement along groomed trails. The historical review provided detail on the gradual consolidation of recreational snowmobile design until the present situation where, in their essential configurations, the snowmobiles of the various marques closely resemble each other.

While snowmobile manufacturers have not entirely ignored the requirements of northern utility users, the tendency has been to modify mid-priced recreational machines for these purposes. At one time, this was understandable in view of the comparative size of the utility market. This is perhaps no more than 10,000 machines per year and, when in the early 1970s, total North American snowmobile output was at its peak of almost 500,000 units, it was not surprising that this sector received only slight attention. Now that the total market has now declined to about 100,000 units, the relatively constant northern utility market has assumed a greater proportional significance.

At present, there is some uncertainty over the future of the snowmobile industry. The main reasons for the severe decline in sales over the last few years have been masked by the effect upon demand of a series of winters with very low

snowfalls between 1979 and 1982. Now, after two winters with plenty of snow, the market has not recovered to its previous levels. The rapid rise in popularity of three-wheeled all-terrain vehicles has no doubt contributed to this decline, especially as these machines perform adequately on some snow surfaces - though they lack the tractive power of snowmobiles. A second major factor is the rising popularity of fitness sports, trail-skiing particularly, at the expense of mechanized recreation.

In this now precarious market, it is interesting to note that three of the four major snowmobile makers, Bombardier Yamaha, and John Deere, all have dominant manufacturing interests elsewhere while only Polaris remains exclusively a snowmobile producer, after having almost disappeared two years ago. Most recently, Polaris acquired John Deere Snowmobiles, reducing the number of major manufacturers to three. Arctic Cat has made a cautious re-entry into the market, producing in 1983-84 a few thousand units to order only.

This study is not only directed towards the design of a strictly utility machine but also examines the feasibility of producing the machine in a kit form. This kit would be manufactured using low capital investment, high labour intensive methods that would be suitable for eventual transfer to northern Canadian communities. The reasons for this are provided in the following section.

1.3. Rationale for Adopting the Kit Production and Marketing Approach

There are five principal reasons:

- Buyers would be able to pre-select the options best suited for their operational requirements and local snow/terrain conditions.
- The sub-assemblies of a kit designed to be easily assembled with ordinary tools could easily be replaced when worn out.
- By passing the costs of final assembly to the buyer, his cash outlay is reduced, an important consideration in many northern communities.
- While a basic snowmobile kit would be available at comparatively low costs, those buyers with the means and interest in a more elaborate and expensive machine may simply order those extra components.
- This approach provides for the eventual possibility of certain assemblies, for example, the chassis, being manufactured using labour intensive technology in the larger northern communities.

The kit approach does not exclude the possibility of providing complete machines to those who require them. In fact. it is conceivable that a turn key assembly business could be developed in a northern community if justified by local demand.

Thus, this design study provides scope for three production/ marketing scenarios:

- Basic snowmobile kits to those who wish to assemble their own machines.
- Kits to those who can establish a business in producing finished machines to order.
- Eventual transfer northwards of basic manufacturing capacity.

The prototypes and first run production machines would be manufactured entirely in southern Canada. Once this process is proven, opportunities will be developed for technology transfer, through provision of assembly jigs, production manuals, training programs, etc.

1.4. The Scope of the Kit Manufacturing Approach

In recent years, a widening range of vehicles have been produced as kits. Often vehicles are initially launched as kits with the more successful marques later evolving as fully assembled machines: the Lotus car is a well known example.

Many ultralight aircraft are supplied as kits, some of which can be assembled in a few hours. Typically, these kits comprise an engine, often derived from established snowmobile engines such as Cuyuna, Rotax, or Hirth, a fuselage, controls, undercarriage, all of which have been manufactured or assembled to the level of sub-assemblies. More conventional and complex aircraft kits have been available for many years. Some of these require the builder to engage in a considerable amount of shop and construction work, with estimated building times varying from 400 to 2000 hours.

In Europe, the interest in kit cars has become so intense that well over a hundred models are in current production in England alone (2). Recent advances in fibreglass technology has made the low volume production of high quality bodywork feasible at acceptable prices. Invariably, these cars use the running gear from a popular 'donor' vehicle and in that sense this mode of production is dependent upon a flow of such vehicles which are derelict by virtue of rusted bodywork rather than general mechanical failure. Nevertheless, there are a few models which are marketed as kits of entirely new components and this reflects a small but growing trend in this industry

one appreciated by the designers who are thus liberated from the configuration developed for a specific donor vehicle.

The mode of production which has evolved in the kit car and aircraft industries closely resembles that proposed for the snowmobile. A kit will include sub-assemblies which have been manufactured to the point where they can readily be integrated into the complete vehicle. These sub-assemblies are composed of parts from two kinds of sources. The more complex components, such as engines, carburetors, and transmissions will have been bought off-the-shelf. Simpler elements, such as body panels, wiring harnesses, and upholstery, will have been specially produced by jobbing contractors. The amount of actual manufacture or assembly undertaken by the kit producing company itself varies considerably according to economies of scale and access to alternate sources.

One company which could well serve as a model for the snowmobile production process is Carl Heald Inc. of Benton Harbour, Michigan. This company produces kits for small scale agricultural machinery and one of their products ranges, of three-wheeled ATVs, is of particular relevance to this study. Not only is this machine of equivalent complexity to a snowmobile, but it closely resembles the Japanese three-wheelers, which for recreational purposes have become competitive with snowmobiles. Figure 1 is reproduced from the Carl Heald Catalogue and illustrates the kind of advance information supplied to the buyer.

An executive of Carl Heald was kind enough to provide some details of the firm's operations. The Benton Harbour facility is only a design and warehousing center. All the components are supplied off-the-shelf or manufactured by twenty-three sub-contractors throughout the United States. At the headquarters, labour is engaged in only two tasks: packing and shipping kits, designing new machines and components.

While kit designers are subject to certain obvious limitations, accessible sources for engines, etc. and the constraints imposed by low volume production, they enjoy certain advantages over large volume manufacturers of finished vehicles. Options or new features can be offered in the catalogue without an expensive commitment to new tooling. The purchase price is estimated for a low volume production run which can be started or stopped at short notice. Some kit manufacturers actually offer the new components in the catalogue before commencing a production run - an extremely cost-effective form of test marketing. This advantage is represented by the wide range of options offered by kit manufacturers and the rapidity with which they can respond to customers' expressed preferences or rejections.

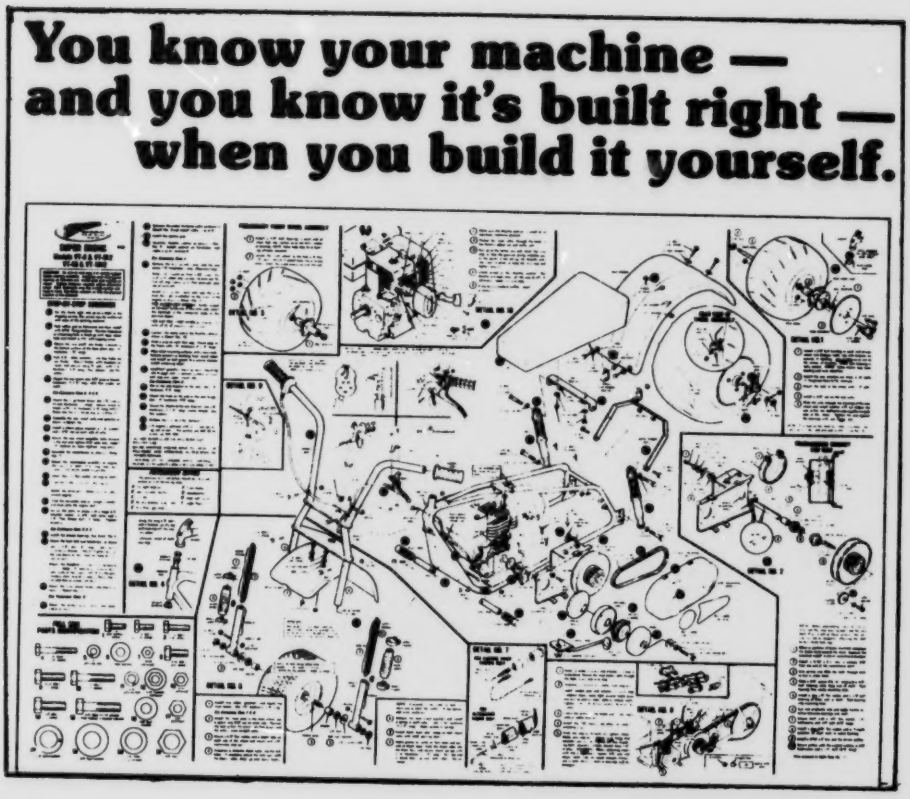


Figure 1 An Exploded View of an ATV Kit by Carl Heald

Source: Carl Heald Catalogue

A second advantage enjoyed by kit manufacturers is that they invariably cater to a small, informed, and critical audience. Such customers are not really in need of the services of distributors or retailers; in fact, they are themselves contemplating taking part in the production process. This situation provides considerable scope for selling kits through a direct marketing process such as a catalogue or magazine. This compresses the typical mark-up sequence significantly and may compensate for the higher costs entailed in low volume production. This question will be elaborated upon in a later section.

1.5. Northern Input and Field Work

Northern users who had provided advice and assistance during the earlier study(1) were kept informed of progress during this investigation. The project was discussed with representatives of the following agencies and organizations:

Northwest Territorial Government Ministries of Economic Development and Tourism (Jim Britton, Deputy-Minister) and Renewable Resources (Jim Bourque, Deputy-Minister), Arctic Cooperatives Ltd (Andrew Grossart, Chief Executive Officer), The Science Advisory Board of the NOrthwest Territories (R.K. Bell, Executive Secretary), Baffin Region Inuit Association (Lucien Ukalianuk, President), Keewatin Inuit Association (Peter Ernerk, President), Makivik Corporation (Mark Gordon, Vice-President). All those informed supported the effort. Appendix B contains samples of discussion material.

On a more practical level, a field trip was made to Northern Québec for the purpose of directly examining the variety of snow/ice/terrain conditions. Taking part were: Jacques Laframboise, Transportation Development Centre, Peter Poole, George Gowing, and Frank Gabbianelli.

In Kuujjuac (Fort Chimo) we discussed the project with Sammy Ekoomiak, Director, Hunter Support Program, Kativik Regional Government. In Kangiqsualujjuaq (George River) Jean-Guy St.Aubin, Atelier Felix, coordinated the visit. This involved detailed review of the project and a lengthy excursion by snowmobile through a wide variety of travelling conditions: deep soft forest snow, sheer ice surfaces, exposed nd boulder-strewn hardpack snow and pressure ridges along the sea coast. The visit ended with a community meeting attended by most of the serious hunters and trappers of the settlement. A three hour discussion of all aspects of the project led to the general suggestion that Kangiqsualujjuac would be the most suitable place to test an eventual prototype, given the local access to such a wide range of ice and snow conditions.

1.6. Principal Factors Affecting Feasibility

From the foregoing discussion, five distinct factors emerge which should all be taken into account in assessing feasibility. In the concluding section of this report, the results will be reviewed in terms of these five. Briefly, they are:

1.6.1. Arctic Utility Performance

To what extent will this machine differ from conventional machines in possessing distinctive capacities? These would include: cold weather reliability, high pulling capability, wide terrain versatility, ruggedness, ease of repair, and short-term flotation.

1.6.2. Availability of Off-The-Shelf Components

Many of the parts could not be economically produced in low volume and must be acquired from other sources. The availability, and specifications, of such components will, to some extent, limit the scope of the design.

1.6.3. Suitability of the Production Process

This process must not only be economic for small scale production but must also be a process which could eventually be transferred to a northern location. This again will set certain limits to the design process as well as providing a further criterion for its evaluation.

1.6.4. Demands of Kit Production

The snowmobile must eventually be suitable for assembly, and repair, with tools that are readily available in remote northern communities. This standard applies especially to the basic chassis of the machine; those in current use on mass production models would not be built in a remote shop.

1.6.5. Marketing and Servicing

The snowmobile kit will be sold through a direct marketing process. Parts will be offered through existing community retail outlets. Owners will have to be largely self-reliant as far as maintenance is concerned. This will also place specific demands upon the designers.

1.7. Organization of this Report

In Chapter 2, various design options are reviewed, leading to the specification of a prototype designed to test the conclusions.

In Chapter 3, consideration is given to the sources of components for such a prototype, both off-the-shelf and through sub-contracting. This leads to a provisional cost estimate for an eventual production machine.

In Chapter 4, the logistics of production, distribution, and marketing are examined, taking into account the effects upon final cost to the purchaser of northern freight rates. In this chapter, preliminary consideration will be given to the eventual options for marketing a utility snowmobile in northern communities.

Chapter 5 contains the conclusions and a recommended course of action.

2. SNOWMOBILE DESIGN OPTIONS

2.1. Introduction: Preliminary Design Criteria

Table 1 lists the preliminary design criteria for a prototype of a utility snowmobile. These were derived in large part from discussions with northern users over the virtues and vices of past and present snowmobiles (1).

Vehicle Weight	175 kg dry (385 lbs)
Komatik(sled) Weight.....	1000 kg (2200 lbs)
Operator Noise	85 db (A) maximum
Fuel Economy (no load) ...	10 l/100 km (27 mpg)
Operating Temperature	-50C to +15C, (-60F to +60F)
Cruising Speed	50 km/h, (30mph)
Top Speed	90 km/h, (55mph)
Buoyancy	short-term floatation
Maximum Vehicle Cost	$3,500 F.O.B. Montreal

Table 1: Preliminary Design Specifications

Respondents to the earlier user study specified 450 kg (1000 lbs) as the minimum komatik (sled) load. Those who used the heaviest machines did so because they could pull double that load. Therefore, it was decided that this machine should be capable of pulling a komatik weighing 1,000 kg (2200 lb).

The top speed is considerably less than that for the faster recreational machinery, but 90 km/h, (55 mph) is still a respectable rate. The cruising speed, of 50 km/h, (30 mph) is the rate at which the snowmobile should pull its specified weight on level hard packed snow.

Snowmobiles are often lost through sinking while travelling across unstable ice. The designers were requested to investigate several options for creating sufficient buoyancy for the machine to float long enough for it to be retrieved. This will not permit the snowmobile to be used as a boat.

Weight will be kept below 175 kg (385 lbs) so as to

improve the chances to obtain such flotation in water and to improve fuel consumption over the rather thirsty levels attained with most snowmobiles. The price of $3,500 is based on that charged for the mid-sized, mid-priced snowmobiles often used for working purposes in the north.

A criterion that is not numerically expressed in Table 1 is the reduction of causes of driver fatigue and discomfort. Cabin design and fan ducting will maximize noise suppression. A high windshield will provide complete frontal protection. Seating will be adjustable and designed to reduce the stress to the spine induced by sqatting on low slung snowmobile seats. The steering column will be adjustable. None of these should impede the driver from kneeling or standing whenever preferred.

In Table 2, the major assemblies are listed, together with their sub-components. This listing is provided as a frame of reference to the following discussion, which deals in turn with the design objectives and alternatives for each assembly.

2.2. Chassis

The tooling costs for producing conventional metal snowmobile tunnels and engine mountings far exceeded the amounts sustainable by low volume production. Instead, we investigated alternatives which would require substantially lower initial investment - though they might result in a somewhat higher unit cost. For this, there were two alternatives: moulded composite materials, tubular steel space frame.

Composite materials possessed two advantages. First, relatively complex shapes could be produced without excessive tooling costs. Second, by developing a sandwich with an interior of balsa wood, the flotability of the machine could be improved.

The space frame also offered two advantages. First, that, ultimately such a unit could be manufactured in a well-equipped welding shop. Second, that the operating strength and durability of steel could be predicted with greater confidence than that of composite materials.

There was extended debate over the relative merits of these two approaches. Doubt was expressed over the abilities of affordable composite materials to withstand the wear and tear of Arctic use, as well as extremely low temperatures. Moreover, it was pointed out that repairs to even a relatively conventional composite such as fibreglass would not reliably restore its strength as a supporting material.

Uncertainty over the Arctic performance of composites led to the suggestion that such a chassis should be reinforced by a tubular space frame. However, this would only partially

CHASSIS	engine sub-frame central sub-frame rear sub-frame engine mounting plate
BODYWORK	hood bellypan chassis shroud windshield seat console bumpers cargo platform kickstand equipment racks
POWER PLANT	engine ccoling system carburation fuel tank/lines ignition system starter exhaust system
TRANSMISSION	clutch drive belt driven pulley chaincase drive shaft brakes
STEERING/SKIS	skis suspension steering
TRACKS/ SUSPENSION	tracks suspension rear shaft/idlers
CONTROLS/ ACCESSORIES	handlebar controls headlamp rear light temperature guage tachometer

Table 2: Major and Minor Assemblies

reduce the liability of composite materials, while at the same time increasing the complexity of the construction.

The final recommendation is for a tubular steel space frame manufactured in two main sections, with the option of adding a rear extension. This approach, which is illustrated in Figure 2, has several advantages. A front element, designed to accept a different engine type, could be mated to the same central element. Equally, a central element, perhaps accomodating a longer track could be mated to a stock front element. A second major advantage is that the jigs for producing such a chassis are simple and cheap and this would expedite the future transfer of manufacturing northwards. Finally, such a frame could be readily repaired with the facilities already in place in most northern communities.

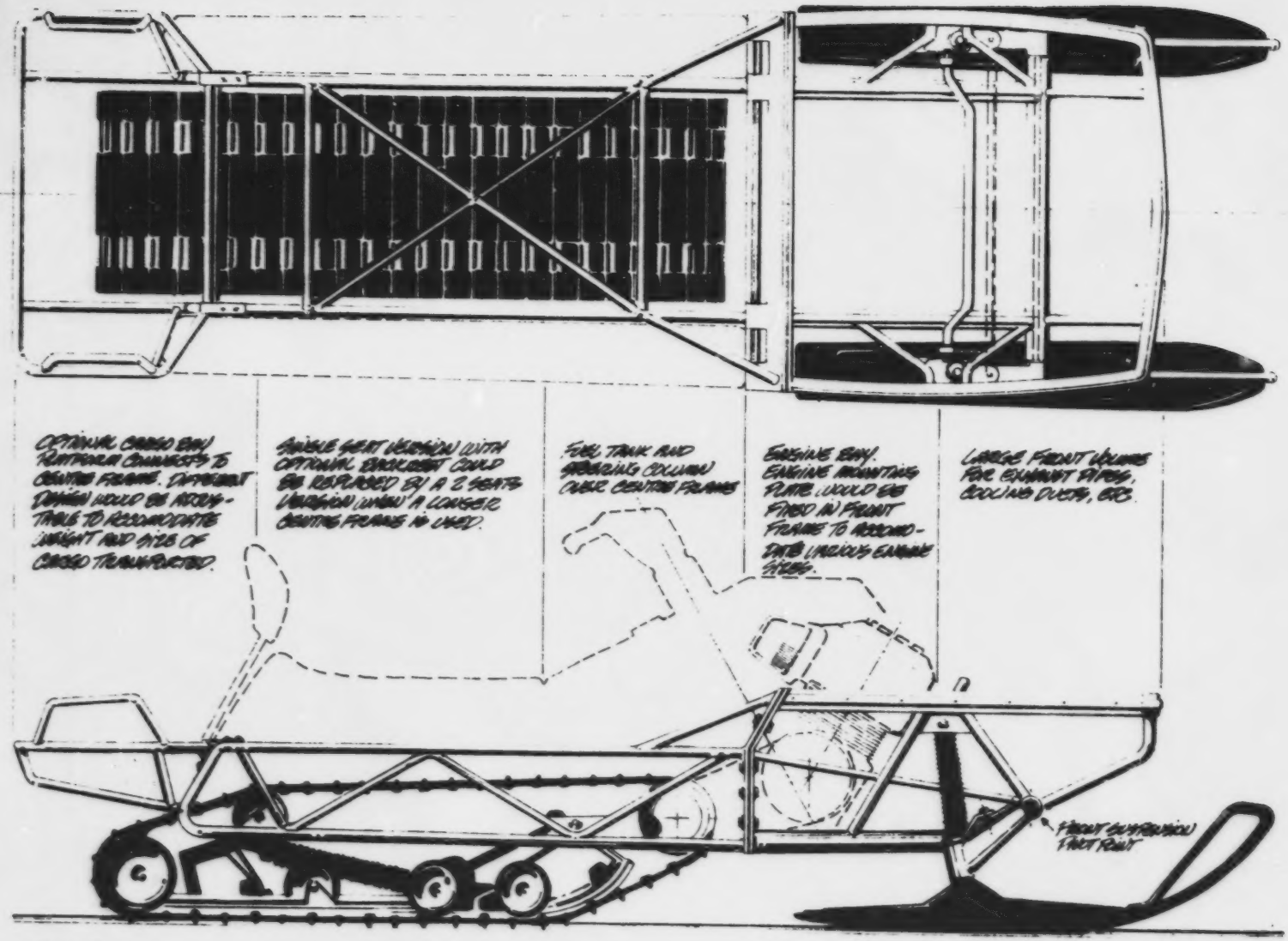
A further point of prolonged debate was the positioning of the engine. In conventional recreational machines, the engine is placed well forward and low; in the past it was often placed directly on the tunnel. While a tunnel mounted engine is simpler in terms of overall construction, the centre of gravity is raised, the steering tends to be less positive, as the centre of gravity is moved backwards. The position shown in profile in Figure 2 is a compromise; the engine is mounted close to the chassis joint, for maximum strength and security, and is placed so as to produce a low centre of gravity.

2.3. Bodywork

Figure 3 illustrates the relationship to the chassis of the bodywork assemblies listed in Table 2. These components would be progressively bolted on to the chassis during assembly of the kit. Since they would not be subjected to such severe stress as the chassis, composite materials could be utilized. These would be limited to hand-lain fibreglass suitable for eventual Arctic manufacture.

The hood, as illustrated in the figure would probably be moulded fibreglass. However, the possibility of forming a more simple shape from mild steel has been left open. The optimum configuration for the hood should incorporate ducting for engine cooling. The bellypan would be produced from composite materials, probably fibreglass. The chassis shroud would be made from either sheet metal or fibreglass. In selecting such materials, their suitability for northern manufacture will be considered as well as their comparative cost.

The sketch in Figure 4 is an artist's rendition of a complete snowmobile based upon the structure illustrated in Figures 2 and 3. It is not intended to represent the shape or styling of the eventual machine. Alternative configurations, also used as discussion material throughout this study, are illustrated in Appendix B.


OPTIONAL CARGO BAY/ PORTHOLE CONNECTS TO CENTRE FRAME. DIFFERENT DESIGN WOULD BE ACCEPTABLE TO ACCOMODATE WEIGHT AND SIZE OF CARGO TRANSPORTED.
SINGLE SEAT VERSION WITH OPTIONAL BACKREST COULD BE REPLACED BY A 2 SEATS VERSION WHEN A LONGER CENTRE FRAME IS USED.
FUEL TANK AND STEERING COLUMN OVER CENTRE FRAME
ENGINE BAY. ENGINE MOUNTING PLATE WOULD BE FIXED IN FRONT FRAME TO ACCOMODATE VARIOUS ENGINE SIZES.
LARGE FRONT VOLUME FOR EXHAUST PIPES, COOLING DUCTS, ETC.
FRONT SUSPENSION/ FRONT RAM
REAR FRAME
DESIGNED TO ACCOMODATE CARGO NEEDS.
CENTRE FRAME
SPACE FRAME, TUBULAR CHASSIS SHOULD BE MADE IN DIFFERENT LENGHTS TO ACCOMODATE LONGER TRACKS. CHASSIS PROVIDES A LOW CENTER OF GRAVITY FOR INCREASED STABILITY AND REDUCED WEIGHT WITHOUT SACRIFICING STRENGTH.
FRONT FRAME
SPACE FRAME, TUBULAR CHASSIS WOULD BE MADE TO MEASURE TO ACCOMODATE DIFFERENT ENGINES.

ARTIC SNOWMOBILE

Figure 2: **FRAME CONCEPT**

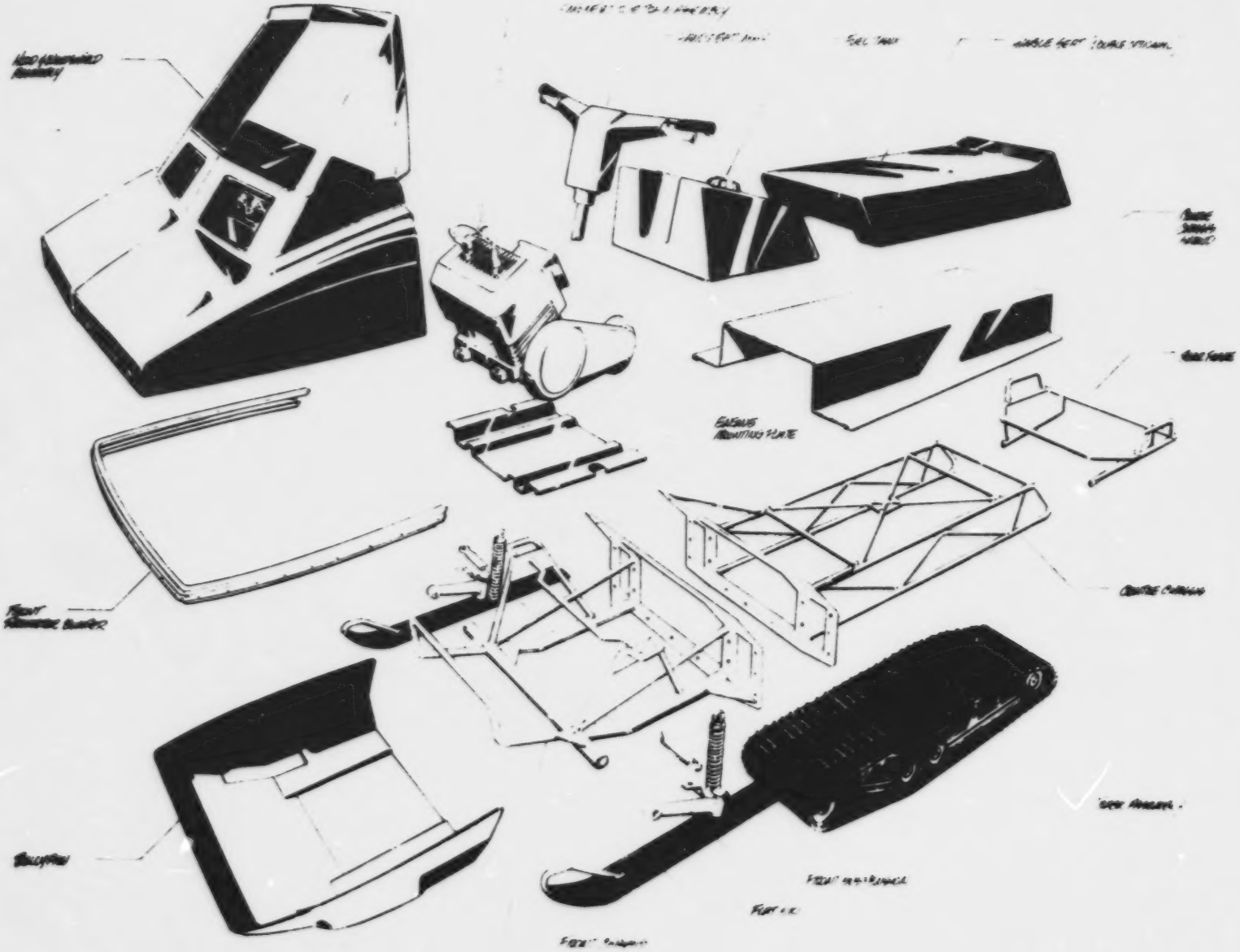


Figure 3:

note: This illustrates one of the visual concepts used for discussion purposes during this study. Other concepts are illustrated in Appendix B.

Figure 4: ARTIC SNOWMOBILE
ASSEMBLED VEHICLE

The windshield will be manufactured from polycarbonate according to specifications provided to a sub-contractor. The shield will be higher than those provided on conventional snowmobiles, affording complete frontal protection while enabling the driver to look just over the top. Optional lateral extension may provide some protection from cross winds. It is unlikely that the windshield could be manufactured in the north.

The basic machine will have a single seat, to which an adjustable back rest may be added. As a kit option, a double seat could be purchased, but this would reduce the onboard cargo space. The seat cover will be fabricated from a woven material, treated to discourage tearing by animals. The seat material will be a closed-cell foam which will contribute to the floatability of the machine.

The front bumpers will be of extruded aluminium with a substantial insert of resilient composite material. As Figure 3 shows, the bumpers will extend around the entire hood assembly, rear bumpers will be of the same design.

Unlike most conventional snowmobiles, the rear cargo deck will be as wide as the hood and various configurations will be offered as kit options. A kick stand will also be provided as a kit option. This would prevent the tracks freezing to the ground overnight, and would also be useful in freeing them of detritus while warming the engine. The towing hitch will be an integral element of the centre or rear chassis elements.

2.4. Power Plant

2.4.1. Engine

The engine is not only the most expensive single component but it is also one with a limited number of potential suppliers, and research into these sources indicated that the reliability and continuity of supply would perhaps be as important as price in deciding which type to use. However, before researching sources, the engineering team specified in general terms a suitable engine.

First, two and four stroke engines were compared. Though four stroke engines are quieter, more economical and more durable, two stroke engines have a superior power to weight ratio and are easier to start in very cold weather. In the past, four stroke engines, and even rotary engines, have been used in snowmobiles, but these basic disadvantages have never been overcome, and all current production machines use two stroke engines.

After considering these alternatives, the team agreed upon

a two stroke engine, of about 400cc., delivering about 35 HP at 6,000 RPM. It was felt that a regular "440" engine, de-tuned for improved reliability and economy would meet the preliminary specifications outlined above.

However, since the chassis design would accomodate engine dimensions in the front element, the possibility of using a four stroke engine as a kit option has been retained. For users who do not require flotation, the weight penalty might be accepted, in exchange for increased durability and economy. Therefore, while the focus will remain on the two stroke engine for Arctic performance, a prototype testing program should include and effort to improve the cold weather starting of an otherwise suitable four stroke engine.

Table 3 lists these engines in current production which fell within the general specifications outlined above.

Manufacturer	Country of Origin	Engine Capacity	Remarks
Rotax (Bombardier)	Austria	368	Against company policy to supply engines to North American snowmobile manufacturers.
Yamaha	Japan	338/437	Not available.
Hirth	Germany	438	No longer used in snowmobiles. Quite expensive.
Skidaddle	England	525	Would require extensive modification. Quite expensive.
Suzuki	Japan	431	Used in resurgent Arctic Cat. Not available in Canada.
Fuji	Japan	432	Used in Polaris and probably future John Deere.
Kawasaki	Japan	436	With John Deere sold, snowmobile engine production may cease.
Cuyuna	USA	430	Once used in Scorpion. Still in production, adaptable.

Table 3: List of Candidate Engines

Of the eight types listed, only the Kawasaki and Cuyuna engines would now be readily available, and, in terms of performance, both appear suitable. However, Kawasaki withdrew from complete snowmobile production two years ago, and have since then only suppled engines to John Deere. With the sale of John Deere Snowmobiles to Polaris, it seems that these will be supplanted by Fuji engines. Therefore, little incentive remains for Kawasaki to continue producing these engines and company officials were unable to provide any guarantees over future supply.

A visit to the Cuyuna Engine Company in Minnesota led to their offering a complete engine package at a quite reasonable rate: US$560 for quantities over 1,000, US$600 for 26-300 units. This package would include the following components along with the engine block:

- recoil starter
- CDI ignition
- intake manifold
- carburetor
- fuel pump
- complete exhaust system

This engine, the twin cylinder ULII-02 has a weight of 26 kg (58 lbs), a displacement of 428 cc. and it is rated at 35 HP at 6,250 RPM. It is derived from a "440" engine once used in Scorpion snowmobiles. It is manufactured in a modern plant using tooling originally made by Rockwell in Germany. The basic engine has been developed for use in ultralight aircraft and currently powers about half the models in production in North America. This development has included flattening of the torque curve, a change which would also benefit its pulling performance in a utility snowmobile. More comprehensive details are provided in Appendix C.

2.4.2. Cooling System

Snowmobile engines are cooled by three methods: free air, liquid cooling, fan-cooling. Free air is the least expensive but is dependent upin vehicle speed to obtain an adequate air flow. For pulling heavy loads at low speeds another approach is required. Liquid cooling improves performance but adds the most weight and expense to the power plant. Fan-cooling was selected as the most cost-effective compromise.

The Cuyuna engine described above has retained the fan-driven cooling system originally developed for use in snowmobiles. The company has expressed a willingness to collaborate in developing a direct-drive fan-cooling system should their engine

be adopted for production in this snowmobile.

2.4.3. Carburetion

All snowmobiles in current production use a Mikuni unit. This is also included in the engine package offered by Cuyuna. In response to suggestions received from some northern users, a fuel primer will be offered as a kit option.

Considerable attention was devoted to the question of whether to use an oil injection system or to rely upon pre-mixing. When first introduced, oil injection systems were frequently the initial cause of considerable engine damage when with temperatures falling to-35°C, the oil thickened to the point where it would not mix with the gasoline. Since then, oil injection technology has improved considerably, to the extent that some users consider it foolproof, even in very cold weather. It certainly does offer significant operational advantages: less oil is used overall, plugs foul less often, and pre-mixing is dispensed with. However, many users still hold strong reservations about such systems and often remove them from new machines.

On the principle of simplicity over complexity, it is recommended that this snowmobile use pre-mixing on the basic machine, while offering an oil injection system as a kit option.

2.4.4. Fuel Tank/Lines

For the fuel tank, two alternatives were considered during early meetings: a molded composite tank made by a sub-contractor, an off-the-shelf tank fo the kind used with outboard motor boat engines. The advantages of the latter appeared to be that the user could carry several spare tanks, with gasoline and oil mixed, on his komatik and simply switch these when required. However, the users with whom this notion was discussed did not think it particularly advantageous and therefore, in view of the added expense and difficulty in accomodating such tanks in the design, this idea was dropped. The fuel lines will be made from readily available materials and are considered to be components that could readily be produced in the north.

2.4.5. Ignition System

Capacitor discharge ignition (CDI) systems have improved to the point where the improvements in starting and performance over contact breaker/magneto systems are sufficient to justify the addititional cost and complexity. For the snowmobile kit the wiring will be of higher quality than that normally used in snowmobiles.

2.4.6. Starter

The machine will use a conventional manual recoil starter. Electric starters entail a considerable weight and cost penalty and add maintenance problems with the introduction of a battery. An electric starting system will be offered as an option, but this will be an expensive item unless the demand is strong enough to support a large inventory.

2.4.7. Exhaust System

A simple can-type muffler will be used. A tuned exhaust system with the potential to increase power output by 10% will be provided as an option.

2.5. Transmission

The conventional, and proven, variomatic snowmobile transmission will be used for the utility machine. Such systems have become increasingly popular for other applications and two suppliers of suitable systems have been located in eastern Canada.

Considerable thought was given to the installation of a two-speed gearbox downstream from the variomatic transmission. This would provide a low range, for pulling very heavy loads, and a high range for travelling without a komatik. Such a unit, also equipped with a reverse gear, has for a long time been in use on the Bombardier Alpine, and it was proposed that one of these could be used on a prototype to test its effectiveness.

However, users with whom this prospect was discussed felt that the advantage conferred by a two speed gearbox would not justify the additional cost and complexity. This opinion was confirmed by the Cuyuna engineers who felt that a 35 HP engine, with a flattish torque curve, would, in a relatively light snowmobile, provide considerable pulling power throughout its normal range. Moreover, it was felt that a reverse gear is only necessary in a heavy machine such as the Bombardier Alpine and those who were accustomed to reverse gearing stated that the skis would have to be re-designed to accomodate backward motion. In view of the generally negative comments from northern users, it is recommended that the addition of a gearbox be deferred until the basic machine has proved its capabilities.

2.6. Steering/Skis

During early discussions, considerable attention was paid to the idea of providing for a set of low-pressure wheels as an alternative to skis. Also, consideration was given to permanently mounting such wheels and mounting optional skis

below the wheels, thus using to advantage the suspension effect of the low pressure tires. Some of the discussion material in Appendix B illustrates this approach.

For those who always travel on hardpack snow, it is conceivable that low pressure wheels would be superior to skis. Three-wheeled all-terrain cycles (ATCs) have now become popular enough in the Arctic for most people to appreciate the capabilities and limitations of low pressure tires. It is significant therefore that the response to this prospect was generally neutral or negative. When prompted, users would respond that any lengthy journey would entail crossing some patches of deep soft snow and there they would run into trouble, from which a wheel equipped snowmobile would be far more difficult to extricate than one with skis. This suggests that ATCs are appreciated for their superior performance in limited conditions but that snowmobiles are considered to provide greater terrain versatility and are thus preferred for more serious work under a wider variety of conditions.

In view of the uniformity of this response, it is recommended that the development of an alternative wheel kit be deferred until the basic machine has been brought to operational standards.

While the steering and ski assemblies will follow the conventional snowmobile pattern, the front suspension will depart from this to some extent. The profile drawing in Figure 2 illustrates a trailing link type of suspension, somewhat similar in operation to the Macpherson strut system used on some cars. The trailing link will pivot from an anchor point on the front chassis element while a heavy duty coil spring will connect the ski support to a rearward anchor point. Besides improving the riding characteristics, it is hoped that this approach will isolate the engine compartment to a greater extent than regular leaf spring suspensions.

2.7. Tracks/Suspension

Considerable discussion was devoted to the possibility of using two tracks instead of one. The Bombardier Alpine and Elite models use twin tracks, but these are two 38.4 cm (15 inch) tracks, identical to those used in the company's Scandic model. The proposal here was to use two 20.5 cm (8 inch) tracks instead of a single track of 41 cm (16 inch). For illustrations of this track arrangement, see Appendix B. For a discussion of the history of snowmobile tracks, see Appendix D.

Those advocating two tracks felt that these would

improve the suspension and traction in that only one track would respond to narrow terrain obstacles, leaving the other to maintain propulsion. Without disputing this effect, those doubtful about two tracks felt that they might in the same way respond unequally to the lateral movement of the rider. As he shifts to one side of the vehicle, the track on that side would tend to dig into the snow surface and in consequence slow down, which in turn would cause the other track to slow down. In twin-tracked racing snowmobiles, this problem was overcome by installing a differential, but this would entail a significant weight and cost penalty.

In favour of twin tracks, it was suggested that the typically higher power losses, produced when transmitting propulsion to a conventional single track, would be reduced significantly. On the other hand, it was argued that some form of differential would be required to realize this potential saving.

A further concern was expressed over the question of maintaining longitudinal alignment with a long thin track. This is a problem encountered by the users of the long tracked machines that have recently been developed for northern uses, and these tracks are about twice as wide as those proposed for this vehicle.

In conclusion, the theoretical advantage of twin tracks, improved suspension and reduced power loss, did not incontravertibly seem to outweigh the apparent disadvantages, increased complexity, and possible alignment problems. Therefore, it is recommended that the emphasis in prototype development be first placed upon a single track, reserving two tracks for later experiment.

2.8. Provision for Floatation

Three options were considered for achieving a limited amount of floatation should the snomobile break through sea ice: inflatable devices, a sealed hull, inherent buoyancy.

Inflatable devices were rejected on the grounds of complexity, maintenance problems, and the difficulty of developing a reliable trigger.

While a sealed hull may in theory be relatively simple to design, one of the most persistent problems with amphibious vehicles is maintaining the seals during every day all-terrain use.

It was felt that temporary floatation could be achieved by introducing buoyant material into suitable parts of the body.

Hence, a three-part strategy has been adopted:

1. The 'hull' will be closed, but not necessarily sealed, to provide an initial slow submergence.

2. Where possible, parts that can be engineered to float without modifying their design or cost will be so designed. This will provide backup flotation at no cost and minimize the amount of buoyancy material required.

3. Closed-cell foam will be formed into all available frame cavities to provide permanent, reusable, flotation.

To estimate the amount of buoyant material that would be required, centre of mass and flotation calculations were completed for a snowmobile of 198 kg (435 lbs). Later, a 209.5 kg (461 lbs) snowmobile was weighed while being submerged in order to verify these calculations. It was concluded that 0.127 cubic meters (4.5 cubic feet) of floatation material would be required to support this snowmobile and a driver of 70 kg (150 lbs) for a limited period. The relevant reports and calculations are added as Appendix E.

In the general design that has been discussed above, there is scope for introducing buoyant material in the seat, the chassis shroud, and at the front of the engine compartment. It is recommended that this be done during prototype trials.

2.9. Controls/Accessories

A minor, but constantly irritating, problem encountered during long Arctic trips is the driver's thumb freezing as a result of its being extended over the throttle lever. Heated handlebar grips have been tried as a solution but have proved ineffective; the rest of the hand remains warm anyway. Two alternatives were proposed. That two throttle levers be provided, so that the driver can switch hands. That a twist grip, similar to those used on trail bikes be used. Both of these are suggested for prototype tests.

One accessory not often installed on snowmobiles is an engine temperature gauge. The collective opinion of those who service Arctic snowmobiles is that a common cause of engine problems is the user not warming his engine properly before starting out. While a temperature quage would not automatically solve this problem, a suitably designed dial could at least inform the driver when he is abusing his machine in this way.

A final option proposed for the kit snowmobile is a pair of headlamps, one with conventional white light, the other using a yellow fog lamp type for improved visibility during snowstorms, twilight haze conditions, or partial whiteouts. A switch will enable the lights to be extinguished while the engine is running.

2.10 Concluding Remarks

The foregoing has summarized the consideration given to design features which represent departures from what has evolved as the conventional snowmobile configuration. Some of these would provide obvious improvements in utility performance; for example, increased load pulling capacity, extended onboard storage space, really protective windshield.

Others appear to offer less obvious, or more controversial, improvements; for example, twin tracks, two-speed gearbox, low pressure wheels. While research and development of the latter group of options is a tempting prospect, it is easy to loose sight of one of the main objectives of this study; to develop a simple, tough, machine which meets the needs of Arctic users and which could eventually be partially manufactured in a northern setting. For this reason, the position has been taken that those departures from conventional design which offer immediate and obvious advantages in terms of Arctic utiltiy performance should be incorporated first in a prototype design, while further development of the less obvious alternatives should be deferred until the basic machine, and the process of manufacturing it, have been firmly established.

The sketches in Appendix B illustrate the variety of basic configurations and body styles that were considered during the investigation before settling on the basic structure. The question of whether the final machine will appear more 'utilitarian' or more 'rakish' will be settled once its mechanical capacities have been proven.

Table 4 summarizes the recommended specificatons for the basic machine and suggests the most appropriate sources for major assemblies. These fall into three categories:

- Obtained complete; e.g. engine package
- Manufactured from raw materials; e.g. chassis
- Assembled from a combination of parts and raw materials; e.g. rear suspension

Sources and costs of these assemblies are considered in greater detail in the following chapter.

COMPONENT	SPECIFICATION/SOURCE
CHASSIS	Tubular steel space frame with steel engine mounting plate. Designed to be manufactured in average metal-working shop.
BODYWORK	The windshield from polycarbonate, to be supplied by a specialized sub-contractor. Other sub-assemblies to be produced from metal or easily worked composites such as fibreglass.
POWER PLANT	Engine package to be supplied by Cuyuna. Fuel tank to be supplied by specialized sub-contractor. Fuel lines, control linkages, wiring harness to be designed for eventual manufacture in northern Canada.
TRANSMISSION	To be supplied complete from manufacturer such as Kimpex or Power Block.
STEERING/SKIS	Skis and suspension elements to be supplied from source such as Kimpex. Some steering components to be manufactured with same facilities as the chassis parts.
TRACKS/ SUSPENSION	Tracks to be supplied by specialist manufacturer such as Kimpex. Suspension elements from various sources, to be assembled eventually in a northern facility.
CONTROLS/ ACCESSORIES	Various sources.

Table 4: Summary Specifications and Sources for Major Assemblies

3. SOURCES AND COSTS OF SNOWMOBILE COMPONENTS

3.1. Introduction

Sources for the components assigned to the basic snowmobile kit fall into three categories:

- Off-the-shelf components such as the engine or temperature guage.
- Sub-contracted manufacture requiring technology unsuitable for eventual northern transfer.
- Sub-contracted manufacture or assembly involving processes suitable for eventual northern transfer.

The first two categories represent dependence upon external suppliers; the third represents the potential for in-house manufacture and eventual transfer of this capacity to northern Canada. Table 5 shows the sources for all major assemblies in terms of these three categories.

Suppliers or manufacturers for all of the major and minor assemblies listed in Table 2 have been located. These sources are discussed further below.

3.2. Sources of Components

3.2.1. Off-The-Shelf Components

It was suggested above that the most suitable supplier for the engine package would be the Cuyuna Engine Company, Crosby, Minnesota, U.S.A. (There are no Canadian manufacturers of two-stroke engines).

For the remaining off-the-shelf components listed in Table 5, suppliers have been located in eastern Canada.

3.2.2. Southern Sub-Contractors Only

The windshield would be most economically produced by a manufacturer with suitable specialized tooling. It is probable that the manufacture of parts for the front suspension snd steering assembly would also require more sophisticated tooling then is available in northern communities. However, it is conceivable that the assembly process could eventually be transferred northwards.

ASSEMBLY/COMPONENT	ESTIMATED COST
Off-The-Shelf	
engine package	800
transmission and brake	285
track	300
skis	75
controls/accessories	80
(sub-total	1,540)
Southern Sub-Contractors Only	
windshield	25
front suspension	50
steering assembly	100
(sub-total	175)
Potential for Northern Manufacture or Assembly	
chassis (all sections)	200
hood	75
bellypan	40
chassis shroud	40
seat/console	65
cargo platform	35
equipment racks	20
kickstand	15
bumpers	30
slide suspension	200
(sub-total	720)
Allocation for kit preparation, freight, packing, administration, per unit	250
TOTAL	2,685

Table 5: Component Sources and Rough Production Cost Estimate for Basic Snowmobile Kit

3.2.3. Potential for Northern Manufacture and Assembly

All the chassis and bodywork assemblies would be designed in such a way that their manufacture could be transferred to northern Canada. For the most part, these assemblies would be manufactured entirely from raw materials, mainly steel, fibreglass, and closed cell foam.

Facilities for welding and sheet metal working already exist in the larger northern communities and it is probable that this process would be transferred northwards before the manufacture of composite material assemblies. However, this would not be the first time that fibreglass manufacture was undertaken in Arctic Canada; in the early 1970s, hand-laid fibreglass freighter canoes were being produced in the settlement of Repulse Bay (population, 400).

The slide suspension would be mostly assembled from pre-manufactured runners, wheels, bar, and shock absorber.

3.3. Cost Estimates for Production of a Basic Snowmobile Kit

The first approximation of eventual production costs presented in Table 5 is based partly on prices provided by potential suppliers and partly on the engineering team's past experiences in costing snowmobile production.

The estimate for a basic snowmobile kit is $2,685. This is comparable, or slightly lower than the current prices for recreational snowmobiles which have been adapted for northern use by the major companies. In the far north, with freight included, such machines retail for around $4,000.

The unit cost estimates have been placed on the high side and refer to production runs of 1,000 units where applicable.

Of this total, about $7-800 could eventually be spent in northern Canada, if manufacturing and assembly could be transferred as suggested above. Some of this amount would be spent upon sub-components, raw materials, and freight, but the larger proportion would be spent upon local labour costs.

4. LOGISTICS OF PRODUCTION DISTRIBUTION AND MARKETING

4.1. Introduction

The conditions affecting snowmobile purchasing and servicing vary considerably across northern Canada. The Hudson's Bay Company is the principal retailer for Bombardier but does not provide any servicing facilities. Other types are retailed through community co-ops or individual snowmobile shop operators who may provide good service but do not have the capital to hold an inventory of new snowmobiles. Prospective buyers must provide the money in advance and are usually obliged to pay high air freight rates for immediate delivery. On the other hand, the Hudson's Bay Company usually brings in snowmobiles by sea lift and often advances credit for the purchase of new machines. John Deere also operated a credit buying scheme until quite recently. Often the availability of easy credit determines a buyer's choice of model rather than the suitability of the machine.

In this chapter, a brief assessment will be provided of the conditions affecting the production and marketing of a snowmobile kit in northern Canada. Suggestions will be provided on how best to adapt to the prevailing regime.

4.2. Location of Production Facilities

It has been recommended throughout this report that initial production be concentrated in southern Canada with the prospect of transferring appropriate manufacturing and assembly northwards as soon as these processes become established. It is recommended that the initial production be established in the Montreal area; this has proved to be a suitable area for access to sub-contractors and sources of off-the-shelf parts.

Shipping costs, both of components and completed kits would be a major determinant of the viability of a northern production centre. In Appendix F, freight costs for a 200 kg consignment (440 lbs) are listed from southern centres to northern communities. This listing suggests that a single production facility in the north would probably be at a greater disadvantage than any single southern location, since east-west shipping in northern Canada tends to be limited and expensive.

Since the design provides scope for northern manufacture and assembly with quite limited facilities

a more realistic long term objective might be the development of a few regional production facilities in the north, in larger centres such as Yellowknife, Churchill, and Frobisher Bay. More precise data on the scale at which such facilities would be viable must await the development of production design and costing schedules - following the prototype development phase.

4.3. Distribution

Appendix F shows the impact upon retail prices of freight rates to northern communities. For example, in the Baffin region the air freight rate from Montreal for a 200 kg package, varies between $472 to Frobisher Bay to $1,206 to Pond Inlet, with an average cost in excess of $700. In contrast, the comparable average for sea lift transport is $55.

Clearly, there is a significant advantage to be gained by using the forward shipping facilities of sea lift. However, this requires a substantial commitment of capital well in advance of its possible recuperation. This is a recurrent problem with the Arctic community cooperatives which are obliged to borrow large sums each spring in order to guarantee supply by sea lift.

If northern manufacture and assembly of snowmobile kits becomes a reality, freight rates will have a critical effect upon viability in terms both of supply of parts and materials to the plant and the subsequent distribution of kits or assembled machines. It may be possible to minimize costs by using sea-lift for relatively heavy and cheap materials such as metal and composite bases and air freight only for relatively light but expensive off-the-shelf items.

4.4. Marketing

It is proposed that a direct marketing approach be eventually adopted for the sale of basic snowmobile kits. The earlier study revealed that the successful penetration of the Arctic market by Yamaha machines was aided significantly by word of mouth accounts of their performance.

The retailing of spare parts has been informally discussed with the Chief Executive Officer of Arctic Cooperatives Ltd. An alternative might be to market spares through the offices of the local Hunters and Trappers Association, many of which operate small repair shops for hunting vehicles and boats. In either case, posters advertising the snowmobile, and the procedure for ordering

a kit will be prominently displayed in a place accessible to all members of the community.

Such a marketing procedure leaves open the possibility of a local organization, such as the Cooperatives, or the Hunters and Trappers' Association, assembling machines to meet any local demand that might arise.

4.5. Effects of Freight Rates and Northern Labour Input on Snowmobile Prices

Table 6 is a hypothetical construction designed to illustrate the comparative impact of freight rates and northern assembly labour on final retail prices. It is based on the following assumptions:

- An average air freight rate of $700 for a 200 kg consignment (see Appendix F).
- An average sea lift rate of $55 for a 200 kg consignment (see Appendix F).
- A profit margin of 15% has been added to all production costs except freight and interest.
- That a northern business would need to borrow money for forward purchase, in order to use sea lift, at the rate of 15%. This loan would extend for a year until all units are sold.
- For people purchasing kits, possible interest payments resulting from borrowing have been excluded from the final price.
- Production costs are based upon the following estimates:
  - $2,700 for a complete kit (see Table 5)
  - $300 for assembling a complete snowmobile from a kit, giving $3,000 for a finished machine.
  - $500 for the labour and overhead required to manufacture components that could be made in the north.

Lines 1-6 contain scenarios where finished snowmobiles only are made available. In lines 1-3 air freight only is used. In these cases, the final price stays the same whether the manufacturing and assembly is performed in the south or the north. However with northern input maximized, line 3, $800 of labour/overhead remains in the north. Line 2, kit assembly only, would provide only minimal benefit and should, in the development process, be regarded as a transitory phase, leading to maximum involvement in manufacturing.

PRODUCTION SCENARIO	SOUTHERN PRODUCTION COSTS			TRANSPORT COSTS			NORTHERN PRODUCTION COSTS		15% PROFIT	PRICE TO BUYER	LINE
	COMPLETE VEHICLE	COMPLETE KIT	COMPONENTS MATERIALS	AIR FREIGHT	SEA FREIGHT	15% INTEREST -ADVANCE PURCHASE	MANUF-ACTURE	KIT ASSEMBLY			
ONLY FINISHED VEHICLES PRODUCED - USING AIR FREIGHT	3,000	-	-	700	-	-	-	-	450	4,150	1
	-	2,700	-	700	-	-	-	300	450	4,150	2
	-	-	2,200	700	-	-	500	300	450	4,150	3
ONLY FINISHED VEHICLES PRODUCED - USING SEA FREIGHT	3,000	-	-	-	55	450	-	-	450	3,955	4
	-	2,700	-	-	55	405	-	300	450	3,910	5
	-	-	2,200	-	55	330	500	300	450	3.835	6
ONLY KITS PRODUCED - USING AIR FREIGHT	-	2,700	-	700	-	-	-	-	405	3,805	7
	-	-	2,200	700	-	-	500	-	405	3,805	8
ONLY KITS PRODUCED - USING SEA FREIGHT	-	2,700	-	-	55	-	-	-	405	3,160	9
	-	-	2,200	-	55	-	500	-	405	3,160	10

Table 6

Production Scenarios with Varying Transport and Labour Inputs

Lines 4-6 repeat the above scenarios but use sea freight instead of air freight. However, the savings achieved are partially cancelled when the money for advance purchase must be borrowed. However, prices are $2-300 less than for scenarios using air freight. The greatest reduction is obtained where northern input is maximized and the borrowing requirement is smallest (line 6). It should be noted that, if the money for advance purchase did not have to be borrowed, the final prices for scenarios 4-6 would be considerably less, $3,505.

Lines 7-10 illustrate the cases where a person buys a snowmobile kit and assembles it at home, thus automatically reducing the cash outlay by $300. It would make no difference to the purchaser whether the kit was manufactured in the south or in the north. However, when sea freight is used, the price falls to $3,160, the lowest in the table.

Conclusions based on the figures given in this table should not be taken too far. Air freight rates actually vary considerably about the average used here (see Appendix F). Local overhead and production costs may also vary from one community to another.

Nevetheless, the table is useful in comparing the benefits of varying production scenarios and in assessing the impact on prices of economic factors which are characteristic of northern economies and have no connection with the intrinsic problems of snowmobile design and manufacture. Two problems stand out among these.

The first is freight rates. The table suggests that any reduction that may be gained in retail price through northern participation in manufacturing or through home assembly may well be cancelled out when air freight is used.

The second factor inhibits the solution of the freight problem, the shortage of capital for advance purchase for sea lift transportation. This is a problem faced each year by many of the long-established Arctic Cooperatives and it is even more severely felt by independent retailers of snowmobiles, outboard engines, etc., who must oblige their customers to not only advance the price when placing the order but also to pay the extra required to cover air freight. To remain competitive, the independents must therefore cut their profit margins drastically. This in turn prevents them from accumulating the capital required for advance purchase by sea lift.

In the case of an entrepreneur wishing to establish a northern snowmobile manufacturing facility, there may be

ways of reducing the penalty. For example, the heavier but cheaper materials required to produce the chassis and bodywork may be brought in by sea lift (line 6) instead of air freight (line 3). In addition, a case might be made for requesting transport subsidies for raw materials as an incentive to the development of northern manufacturing business, but this study has been confined to evaluating economic feasibility without reliance on such support.

The optimum scenario for a northern enterprise would appear to be a combination of lines 6 and 10, where the entrepreneur is not obliged to borrow the money for advance purchase. Finished snowmobiles could then be retailed for $3,505 and snowmobile kits for $3,160.

Current economic and political developments in the north provide some scope for overcoming the problem of shortage of capital. With the settlements of Comprehensive Land Claims, aboriginal organizations are receiving sums large enough to initiate an enterprise such as this without incurring a debt penalty. There is scope for a joint venture between a native development corporation assuming responsibility for southern supply and a community-based enterprise the manufacturing of kits and finished machines.

In such a venture, the northern community economy would benefit considerably from maximum involvement in the production process: southern input would be limited to the acquisition and storage of those components which could not be manufactured in the north. This function would be accompanied by a process of design evolution as new components become available or as northern users make suggestions for increasing the efficiency of the machines.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

- That a utility snowmobile suitable for Arctic operation could be produced from a combination of off-the-shelf and sub-contracted components at a cost competitive with those machines currently identified as working snowmobiles.

- That a substantial proportion of those components supplied by the sub-contractors to specification could eventually be manufactured in suitable northern locations using local skills and relatively low level production technology.

- The transfer of manufacturing capacity northwards would not necessarily result in lower prices to the consumer but it would bring considerable benefits to northern community economies as a whole, both by providing employment and by retaining a higher proportion of expenditures within the local economy.

- That by designing for labour intensive production, rather than mechanized mass production, provision is made for continued refinment and evolution of the basic vehicle without incurring excessive capital costs for each new development.

- That, in continuing with this unconventional approach to snowmobile manufacture, it is more important initially to establish the validity of this labour intensive process than it would be to introduce radical technical changes. Experiment with such innovations should follow and be contingent on the successful establishment of this mode of production.

5.2. Recommendations

- That the development proceed to the next stage: construction of and testing of two prototype machines according to the specifications arrived at in Chapter 2 and summarized in Table 4. These prototypes would include several departures from conventional snowmobile design which are considered to have promising applications for Arctic utility use: flotation capability, tubular steel space frame, trailing link front suspension, and a 4 stroke engine as an option to 2 stroke.

- That northern field trials take place in the settlement of Kangiqsuallujjuac, Northern Quebec, following upon the invitation of the hunters and trappers of that community.

LIST OF REFERENCES

1. Snowmobiles as Utility Vehicles in the Arctic: Current Performance and Prospects for Improvement May 1982, By Peter Poole, for the Transportation Development Centre, Transport Canada, File No. TP 3652

2. Kit Car Guide, 1984, P. Philby, Published by Alternative Cars Ltd. Tadworth, Surrey, England

Appendix A

SUMMARY PAPER OF PREVIOUS SNOWMOBILE STUDY

SNOWMOBILES AS UTILITY VEHICLES IN THE ARCTIC: PRESENT PERFORMANCE AND PROSPECTS FOR IMPROVEMENT

Transportation Development Centre

Transport Canada

This paper is an abbreviated version of a Full Report, of 144 pages produced by Transport Canada (Rep. No. TP3652) in English. Summary reports are also available in French (TP3728F) and English (TP3728E).

P.J. Poole, Ph.D.
September 1982

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The design and production of snowmobiles is certainly dominated by the need to serve the recreational market, but a long-term, and continuing decline in that market is obliging manufacturers to pay more attention to the requirements of the very small but comparatively stable Arctic utility market.

2. This market is now being served by modifying certain recreational models and presenting them as "dual-purpose" machines. Thus, the potential for responding to utility requirements is limited by the scope these recreational models provide for modification.

3. The modifications undertaken by manufacturers are limited in that sense and also by the economics of production: how to produce small volume models or features at acceptable prices.

4. The methods by which snowmobiles are now produced prohibit the possibility of designing and manufacturing an entirely new utility snowmobile. For such purposes, users must rely upon two utility models that have been in production for over ten years.

5. The developments and changes that have occurred in the course of refining snowmobiles for recreational use have not always been disadvantageous for utility use, but, it appears that certain avenues of research which could have improved utility performance may have been inevitably passed by in favour of those with more promise for recreational performance.

6. The dual-purpose models recently introduced are providing improved utility performance, but not at lower cost. In fact, the continuing escalation in costs of acquisition and operation is likely to become the dominant factor in selecting future snowmobiles.

7. There may be scope for the small-scale production of a mid-size utility snowmobile if this were done by a simplified modular process of assembly. Such a machine might follow early snowmobiles in basic concept but would take advantage of improved technology and materials. It would not possess the speed or styling typical of current models.

Recommendations

1. If Conclusion No. 7 is to be acted on, the first step should be a study of its practical and economic feasibility and a comparison of the results with the production economics of present manufacturers.

2. This first step in a possible R&D program should only be undertaken if an Inuit or other organisation with a committed interest in the further development of the high Arctic assumes responsibility for coordinating such a program and acting as the interface between technologists and Inuit users.

1. INTRODUCTION

> Over the past years the different manufacturers have invested untold moneys developing stable, fast, comfortable snowmobiles. Weight has always been a factor in gaining the final results. The lighter the final production unit is, the faster is eats up the trails, manoeuvers turns and moguls and results in an overall more comfortable riding machine.
> The original production machines that most of us cut our teeth on could be described as nothing more than anchors. They were assembled with heavy materials for a good reason - the type of terrain the selds were called upon to cover. As much as we hate to admit it, before the trails systems became as expansive as they are today, the open fields, lakes and yes, even paved roads were the main snowmobile t[illegible]s. . . .
> In order to stand up to t[illegible]ype of punishment, the sleds were over-built. Today, what m[illegible]t be a thin aluminum bracket, had to be made of steel plate 15 years ago.
>
> "Snowmobile Canada", 1982, 13(2):42-43
> (emphasis added)

The sentiments expressed in this quotation, and the snowmobile design changes they reflect, have precipitated the study described in this report. Fifteen to twenty years ago, the "anchors" were the mainstay of the snowmobile market. But this market was limited to those who required snowmobiles as working or utility machines. But the demand for utility machines was soon overtaken by an escalating demand for snowmobiles as recreational machines and, once the basic design configuration became established, further technical evolution was dominated by the requirements for accomplishing well-organised travel along well-groomed trails with style, speed, comfort and safety. In the course of this design evolution, the requirements for snowmobiles as utility machines were largely neglected and, at present, the only advertised working machine on the market is a survival from the era of the "anchors".

This situation led to this investigation into the prospects for the "Development of a vehicle for light transportation tasks in the Arctic having an improved performance compared to modern snowmobiles." To achieve this, the study was designed to examine the industry which produces the snowmobile as well as the views and comments of those who sell, repair and use them in the Arctic. The study was being undertaken by the Transportation Development Centre of Transport Canada in collaboration with the Arctic Transportation Directorate. The area of primary concern was snowmobile use north of the tree-line in the NWT and Quebec, while taking note of the needs of communities along the tree-line.

2. THE SNOWMOBILE INDUSTRY: 1960's TO THE PRESENT

Three major trends are apparent during this period. (1) A sharp sales increase of 600% between 1968 and 1971, followed by a continual decline - interrupted only by a slight recovery between 1977 and 1979. (2) A steady decrease in the number of snowmobile producers and models produced. (3) A gradual convergence in the basic design of snowmobiles.

With excellent snow conditions 1981/82, it was hoped that sales would recover to 1977-79 range. But latest figures indicate a continuation in the decline. Apparent reasons are:

1. Economic: increasing prices of new machines and spares.
2. Economic: general recession and high interest rates; withdrawal from luxury purchases.
3. Economic: rising fuel costs.
4. Competition from 3-wheel off-road motor-bikes which can use snowmobile trails but also have greater terrain versatility and cost less. 3-wheeler sales may exceed snowmobile sales this year.
5. Poor image of snowmobiles due to past problems with, noise, safety, environmental impact. Though these have been mitigated, it is conceivable that the sport attracts fewer new adherents.
6. Increasing popularity of cross-country skiing as a cheaper alternative promoting physical fitness.

Northern markets reflect fluctuations experienced in total market to a degree but also show signs of comparative stability: For example, recent sales recovery has been more complete and levels are approaching those of the peak years. In addition, sales over the last five years have been more steady, with those in the NWT & Yukon actually on the increase. Though northern markets are comparatively low in volume, as a proportion of the total market they are increasing and, in fact, this proportion is at present at its highest level ever.

Over the period 1970-83, the number of manufacturers fell from 38 to 4 and the number of models from over 250 to about 40. Many current models are distinguished only cosmetically from each other and share many basic features. This applies particularly to the track which has narrowed progressively to the common dimension found to be most suitable for recreational snowmobiling on groomed trails.

3. THE SNOWMOBILE INDUSTRY NORTH OF THE TREE-LINE (NWT & QUEBEC)

Snowmobile sales and distribution are dominated by three systems. The Hudson's Bay Company buys Bombardier machines in bulk and retails them in most communities. The NWT and Quebec co-operative systems retail John Deere and Bombardier machines through many community outlets. Recently, Yamaha has extended its number of dealerships, some of whom are now co-operatives. Polaris is represented by very few dearlerships. Otherwise, individuals may undertake casual or 'one-time' dealing in snowmobiles.

Repair facilities and qualified mechanics are rare. As a rule, neither the H.B.C. or Co-operative stores maintain repair facilities or keep mechanics on staff. This can lead to problems in the assessment of and compliance with warranty claims. In contrast, mechanics and repair facilities are more likely to be found at the independent Yamaha dealerships. However, many owners prefer to carry out their own repairs and would prefer access to facilities over availability of mechanics as a way of improving the situation.

The supply of spare parts can be a serious problem. While 'routine' parts (e.g. plugs, belts, sliders) may be readily available, owners may have to wait for several months for less ordinary replacements, for example, those that may be needed to overhaul a machine for a second year. Many owners estimated that replacement costs through a season of 'serious' use could reach as high as $500. Estimates of the cost of overhauling a machine for a second year of use may approximate half the cost of a complete replacement machine. This, coupled with the problem of getting the required parts and the comparative unreliability of an overhauled machine, contribute to owner's decisions to replace a snowmobile each year if possible.

An approximation was attempted of the size of the snowmobile market north of the tree-line. To obtain the data, shipment figures were obtained from one manufacturer. To supplement this, all H.B.C. and Co-operative stores or organisations were contacted, some of whom were disinclined to provide data. The final estimate is in the range 1,500-1,600 for the study area. When compared with current population estimates, NWT shows 1 new machine for each 16 inhabitants, Quebec 1 for each 13. Compared with estimates of the numbers of "adult hunters", the sales figures approximate, in the NWT, 1 new machine for every 2 hunters, in Quebec, 1 for every 1.5 hunters.

All four surviving manufacturers have made recent efforts to discover and respond to the needs of the Arctic utility market. Polaris consulted users in Alaska, and then modified two current models as utility prototypes. Regional dealers approved of the design but were discouraged by the prices from ordering any. John Deere consulted Canadian Inuit and produced the Arctic Trailfire Special. This is now available at a higher price than the current model from which it was derived. Yamaha conducted research in Alaska and Canada leading to the production of the 340 TF "Trapper" model, now available. Bombardier conducted research in Canada and Scandinavia, leading to the Scandic and Nordik models. Arctic Cat had designed the Long-Track Jag for the Scandinavian users, since withdrawn from production.

Collectively, the special features on these machines represent not just those requested by Arctic users but also those which could be accommodated within the economics of production of the manufacturers. Such economics exclude the possibility of increasing track widths, but include the following features: longer tracks, enlarged windshields, extra idling wheels, fuel primers, reinforced front suspensions, kick stands, stronger towing hitches, on/off light switches, fuel shut-off valves, de-tuned engines, reduced gearing. These machines tend to be advertised as "dual-purpose" rather than utility machines. They are modified existing models, as manufacturers have stated that the market for a completely new utility vehicle is too small to support its production.

4. INUIT USAGE

> When they started getting skidoos, people decided that they could not keep their dogs going. When you try to keep dogs, the policeman just shoots them, so we turn to metal things that cannot be shot. You break them up yourself, or bump somebody with them. . . . By using a skidoo as your means of transportation, you tend to sharpen your own senses: smell, eyes, your sense of direction in the dark or in a storm, and your prediction of weather. These things were not really sharp before, because you had dogs. If you were going to go somewhere, they would probably know which way to go anyway, because all the things you knew went to the leader and he recorded where he had been before. Dogs used to be valuable for ice. Today, you cannot get a skidoo to walk on different kinds of ice. You have to try and analyse that ice yourself, before you go on it with the skidoo. That way you sharpen your sense - senses that were not so sharp before.
>
> William Kalleo, Nain, Labrador,
> as quoted in "Our Footprints are Everywhere"
> Ed. by C. Brice-Bennett, Labrador Inuit Assoc.
> Labrador, 1977, p. 323.

The most consistent distinction between Inuit use and southern recreational use is that snowmobiles should be capable of pulling heavy loads over considerable distances, over terrain which is far rougher than groomed trails for which the machines are designed. Major types of use are listed below, with the proviso that any single journey may combine any of these activities as circumstances permit or as the opportunities arise.

1. Fishing through lake or sea ice, usually entailing journey over the sea ice to and from the fishing place.
2. Hunting for caribou, musk oxen or wolf, sometimes involving long, unpredictable, trips over land and sea ice surfaces.
3. Hunting whales, seals, walrus and polar bear. Mostly travel over sea ice.
4. Trapping, entailing long, regular journeys, often with heavy loads of traps, spare parts, fuel and supplies.
5. Travel between settlements or between settlements and outpost camps, sometimes involving the transport of heavy loads of supplies, especially to outpost camps.

Everyday travelling conditions are consistently more severe than those for which most snowmobiles are designed. 'Normal' tundra snow surfaces in Canada are considerably harder and more damaging even than those in Scandinavia, and, even when the snow cover is most extensive, a traveller will encounter unavoidable stretches of rock outcrops, gravel, etc. During the spring, terrain conditions are at their worst: on the land, softened snow, mud and exposed tundra; on the sea ice bare rough and ridged ice, collected meltwater and open leads.

Most respondents estimated that a snowmobile would not provide longer than a single season of "serious" or "regular" use. After such a season, a snowmobile, after an overhaul, would be suitable for use around the settlement, or as a back-up machine, but cannot really be depended upon for long trips. Even those full-time trappers on Banks Island, who use the expensive utility Bombardier Alpine, prefer not to use a machine for a second year on the trap-line. Many respondents reported that they could not always afford to obtain a new machine each year but the ratios of hunters to new machines provided in section 3.4.4. suggest an average life-span in the range 1.5-2.0 years.

When asked what kind of distance could be considered serious use, most respondents replied in range 8,000-16,000 km (5,000-10,000 mi) though a few estimated higher or lower. As points of comparison, Hydro-Quebec withdraw their Bombardier Alpines after 7,200-10,800 km (4,500-6,750 mi) - or 2 years of cross-country work; manufacturers estimates of the life-span distance of recreational snowmobiles varied between 11,520 and 17,920 km (7,200 and 11,200 mi).

5. SNOWMOBILES AS WORKING VEHICLES IN THE ARCTIC: COMMENTS UPON PERFORMANCE AND POSSIBLE SCOPE FOR IMPROVEMENT

Snowmobile dealers and mechanics consistently offered the following general comments on the performance and reliability of snowmobiles under Arctic conditions.

1. That in terms of reliability, snowmobiles nowadays are less troublesome than they used to be.
2. That the problems that do develope are usually due either to the extreme severity of the operating environment, or to improper care and maintenance on the part of owners.
3. It appears that, with the appearance of more dependable machines, users concerns may be shifting from reliability to utility performance and longevity.
4. The performance features most in demand were tractive power and capability over a wide range of operating conditions.
5. Reliability was distinguished from longevity. A machine could be considered dependable but only for a limited period, before the probability of breakdown became unacceptable for serious use.

The most knowledgable users understood that the principle orientation in snowmobile research and development was recreational and for that reason were not surprised that machines could not take the wear and tear of Arctic operation. Nevertheless, they did not dismiss all recent developments as impairing utility performance, but pointed out that some were of benefit for both recreational and utility use. When applied to major components of snowmobiles, this distinction prompts the following comments:

1. Engine development has been directed towards improving power to weight ratios and reducing noise. As a result, twin cylinder engines have replaced single-cylinder types, with a loss of torque. However, current engines are superior in terms of fuel efficiency and reliability. Manufacturers are presently aiming at increasing fuel efficiency still further, and, for some dual purpose machines, single-cylinder engines, or de-tuned larger engines will be made available.
2. Cooling systems development has also aimed at increasing power output and reducing noise and liquid cooling once tended to displace free-air for this reason. This system carries a cost/weight penalty. Subsequently, fan-cooling improved and is replacing liquid cooling, except for high performance machines. Fan-cooling is the most cost-effective method for utility use.
3. In fuel supply, the most significant change has been from premixing to automatic mixing with oil injection systems. Users were equivocal about the benefits of oil injection. Early systems would fail at very low temperatures and lead to engine seizure. Improved systems employ more miscible, and expensive oil, but some users still prefer to rely on pre-mixing. Carburetion has improved significantly over the years, with better cold starting, smoother operation and lower fuel consumption.
4. Ignition systems have, over the years, largely converted from contact breaker/magneto types to capacitor discharge systems. At first, these were unreliable and frustrating to repair on the trail. They have since improved and the performance they deliver is preferred to that of breakers.

5. Starter systems are either manual, electric or dual. Electric systems entail a cost/weight penalty and introduce the problem of battery maintenance on cold weather. They were not regarded as necessary for utility use.

6. The engine mounting has progressively moved forward, off the tunnel (the basic structural element) and to the bottom plate, which now supports both the engine and the front suspension and skis. This has entailed much reinforcement of the plate and its attachments to the tunnel. While a forward mounted engine improves steerage, both on grromed trails and tundra snow, such an improvement could be achieved by extending the tunnel forward; the low-slung engine mounting has been developed largely for 'styling' reasons. Low-slung engines do not improve utility performance, in fact they may expose the engines to more damage in rough terrain.

7. Transmissions have improved considerably over the years as manufacturers have learnt from practical experience how better to calibrate the systems. The final transmission of power to the track through the final drive sprocket has improved with the addition of free-wheeling idler wheels and improved track materials.

8. Suspension systems have undergone a general transition from bogie to slider systems. Sliders provide better performance on groomed trails, particularly at speed. They have longer travel, improving comfort and reduce track wear through deformation. However, they are more expensive than bogies. Bogies are toughter and allow travel on a wider variety of terrain types, but are responsible for inducing fatigue and sometimes back injury. A research program to improve the riding qualities of bogies systems could improve utility performance by broadening terrain versatility at lower costs. However, once the commitment to sliders had been made such a program would have been redundant as far as recreational performance is concerned.

9. Three track types have emerged over time: (1) internally, reinforced rubber, (2) rubber with external metal cleating, (3) moulded plastic. The first type has proven to provide the best all-around performance, for recreational and utility uses.

10. However, changes in track dimensions have not been of comparable benefit for utility use. Table 3 shows the convergence in track width that has occurred over the years. Most users consulted in this study held the view that tracks should be wider. For utility usage, the manufacturers have lengthened tracks instead, a more economical measure. It remains to be seen which approach is the more effective.

11. Changes in snowmobile bodies have been chiefly in the materials used and the actual shape. Aluminium, fibreglass and polycarbonate materials have all been introduced without any special benefit for utility performance. Seat design has improved considerably, to some extent in compliance with safety standards designed to reduce impact on the riders' backs.

Consideration was given to snowmobiles which: were advertised or projected as dual-purpose machines, had acquired a reputation as such, or were the most economical. Most of these machines have derived benefits from design and engineering advances since the 1960's as far as engine efficiency, cooling, carburetion, ignition and track materials. However, with regard to body design, engine mounting, track dimensions and suspension systems, the dual-purpose machines, in their 'utility' role, have been limited by the scope for modification exhibited by these design elements on the recreational models from which they were derived.

6. SCOPE FOR IMPROVING UTILITY SNOWMOBILES THROUGH AN R&D PROGRAM

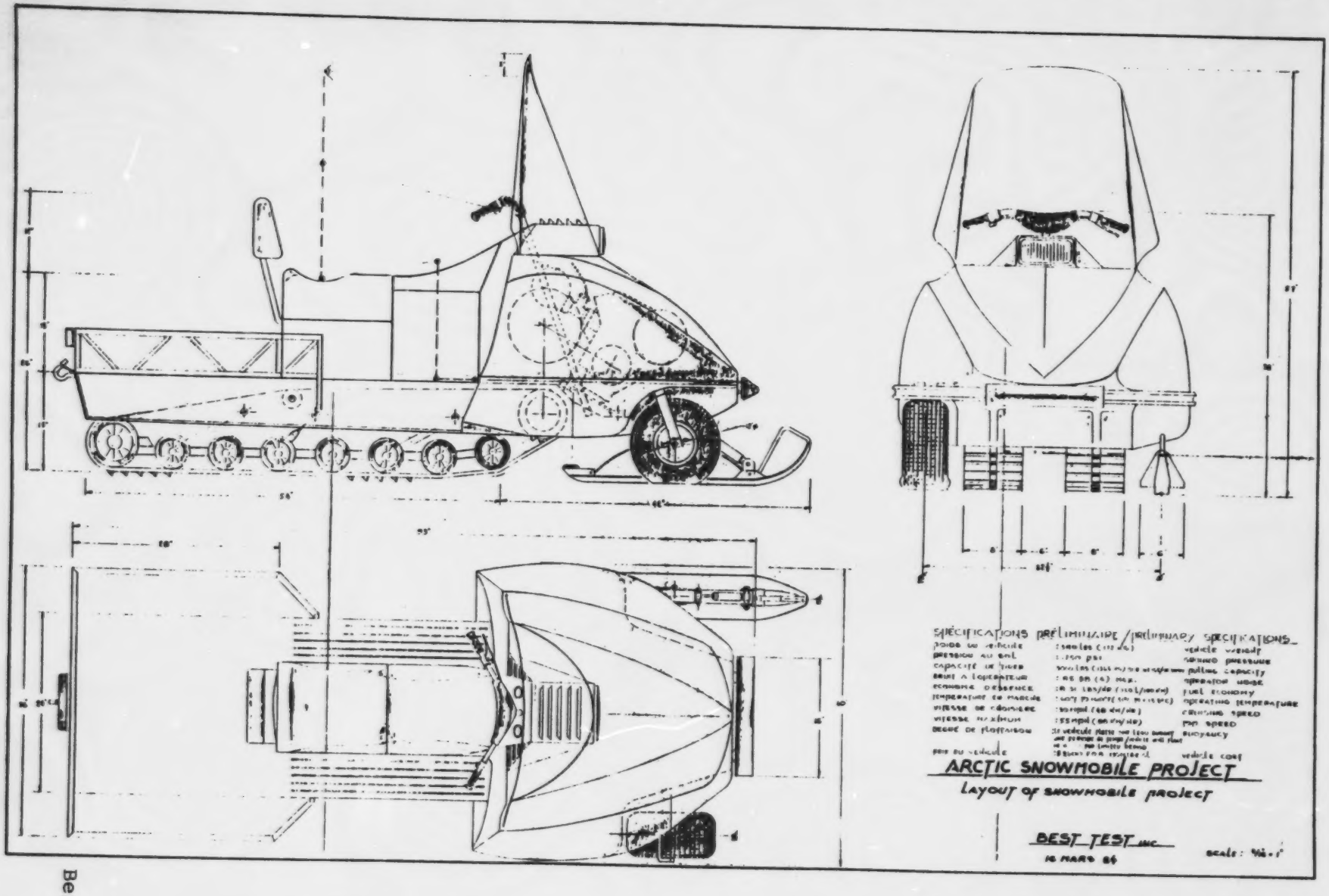
An R&D program could at first have two principle objectives. First, an investigation of the economics of producing a utility snowmobile through a simplified modular assembly process and a comparison of those economics with the production processes employed by the current manufacturers. Second, an investigation of those avenues of research into utility performance that have received low priority during the development of the recreational potential of snowmobiles.

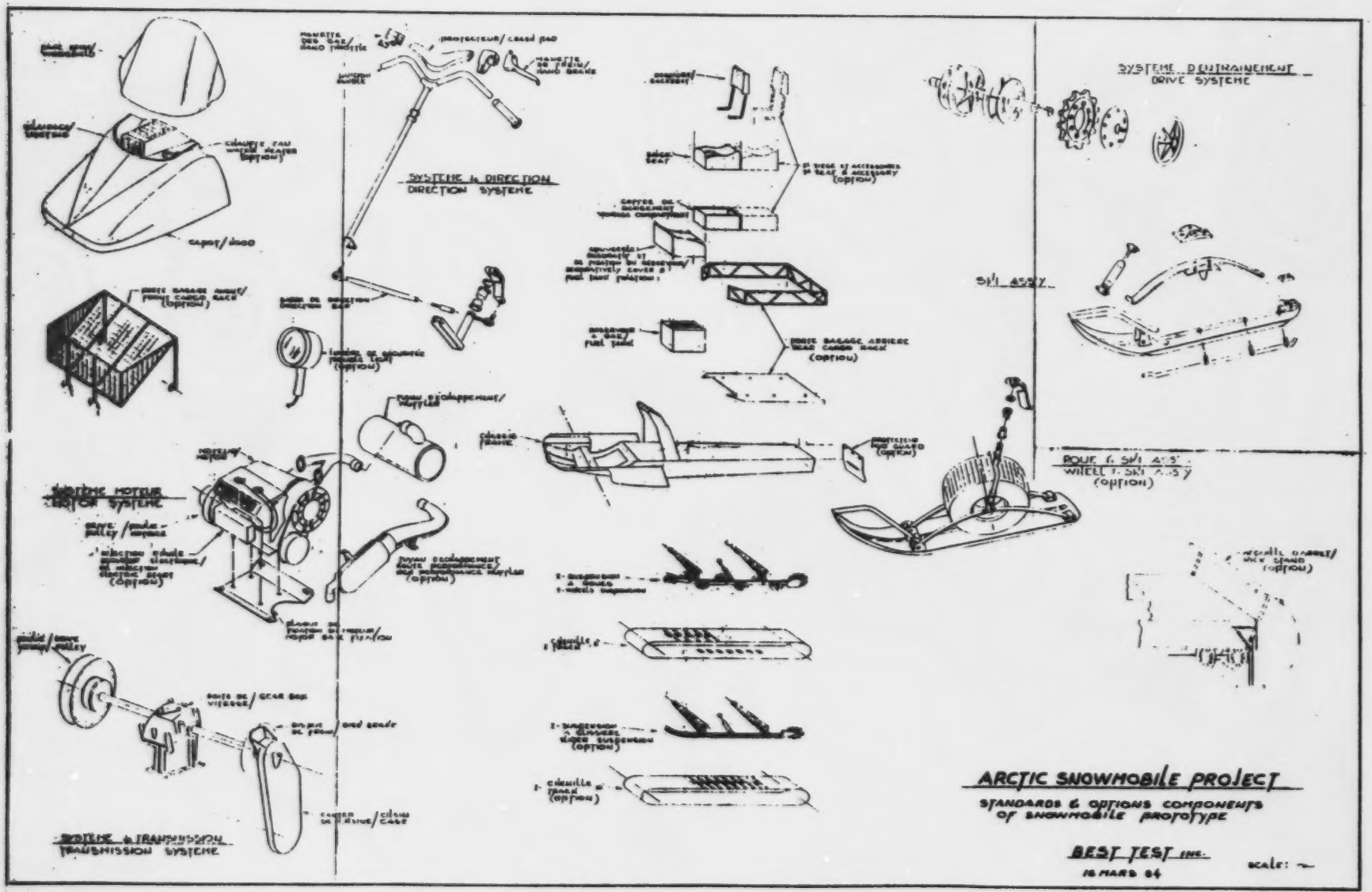
To give concrete shape to the possibilities, "outline specifications for a mid-size modular utility snowmobile" were proposed. These specifications suggest how the technical advances that improve utility performance, and advances in materials, may be integrated with the simplicity of construction of the 1960's. The resulting machine would be simple, durable and readily overhauled, but would be ugly and slow compared with current dual-purpose machines. To be competitive, it would probably have to offer significant advantages in utility performance and costs. In collaborating on such a project, and in generating acceptance, there is much scope for participation by Inuit.

Appendix B

EXAMPLES OF DESIGN VARIATIONS ON UTILITY CONCEPT

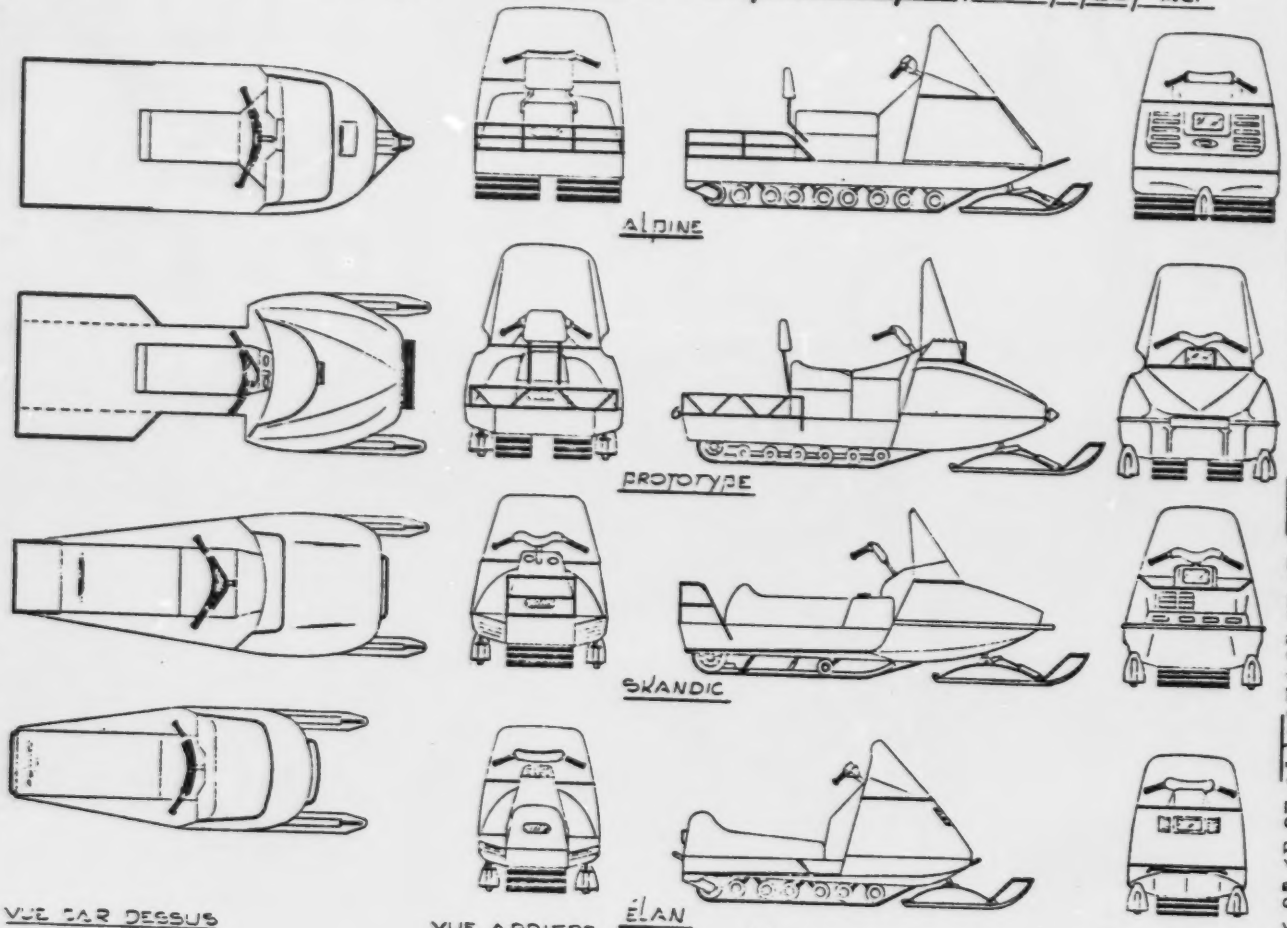
- Best Test design, used in discussions with northern users
- TDC concept for a utility machine
- GSM Design's concept


SPÉCIFICATIONS PRÉLIMINAIRE / PRELIMINARY SPECIFICATIONS
ARCTIC SNOWMOBILE PROJECT
LAYOUT OF SNOWMOBILE PROJECT
BEST TEST INC.
16 MARS 84


SYSTEME DE DIRECTION
DIRECTION SYSTEME
SYSTEME DE TRANSMISSION
TRANSMISSION SYSTEME
SYSTEME D'ENTRAINEMENT
DRIVE SYSTEME
SKI ASSY
ROUE & SKI ASSY
WHEEL & SKI ASSY
(OPTION)
ARCTIC SNOWMOBILE PROJECT
STANDARDS & OPTIONS COMPONENTS
OF SNOWMOBILE PROTOTYPE
BEST TEST INC.
16 MARS 84
scale:

16 MARS 84

ARCTIC SNOWMOBILE PROJECT BY BEST TEST INC.



DESCRIPTION DE COMPARAISON
COMPARED DESCRIPTION

ALPINE	
MOTEUR MOTOR	425 cc
PRESSION AU SOL GROUND PRESSURE	.298 psi
POIDS WEIGHT	442.5 LBS
RÉSERVOIR D'ESSENCE GAZ TANK	5.0 imp. gal.
VITESSE MAX TOP SPEED	40 mph ±
COÛT COST	$6.200.
PROTOTYPE	
MOTEUR MOTOR	400 cc
PRESSION AU SOL GROUND PRESSURE	.250 psi
POIDS WEIGHT	380 LBS.
RÉSERVOIR D'ESSENCE GAZ TANK	7.0 imp. gal.
VITESSE MAX TOP SPEED	55 mph.
COÛT COST	$ 3,500.
SKANDIC	
MOTEUR MOTOR	368 cc
PRESSION AU SOL GROUND PRESSURE	
POIDS WEIGHT	386 LBS
RÉSERVOIR D'ESSENCE GAZ TANK	6.25 imp. gal.
VITESSE MAX TOP SPEED	50 mph ±
COÛT COST	
ÉLAN	
MOTEUR MOTOR	250 cc
PRESSION AU SOL GROUND PRESSURE	.263 psi.
POIDS WEIGHT	285 LBS
RÉSERVOIR D'ESSENCE GAZ TANK	3.0 imp. gal.
VITESSE MAX TOP SPEED	45 mph ±
COÛT COST	$2.000.

Best Test. 3

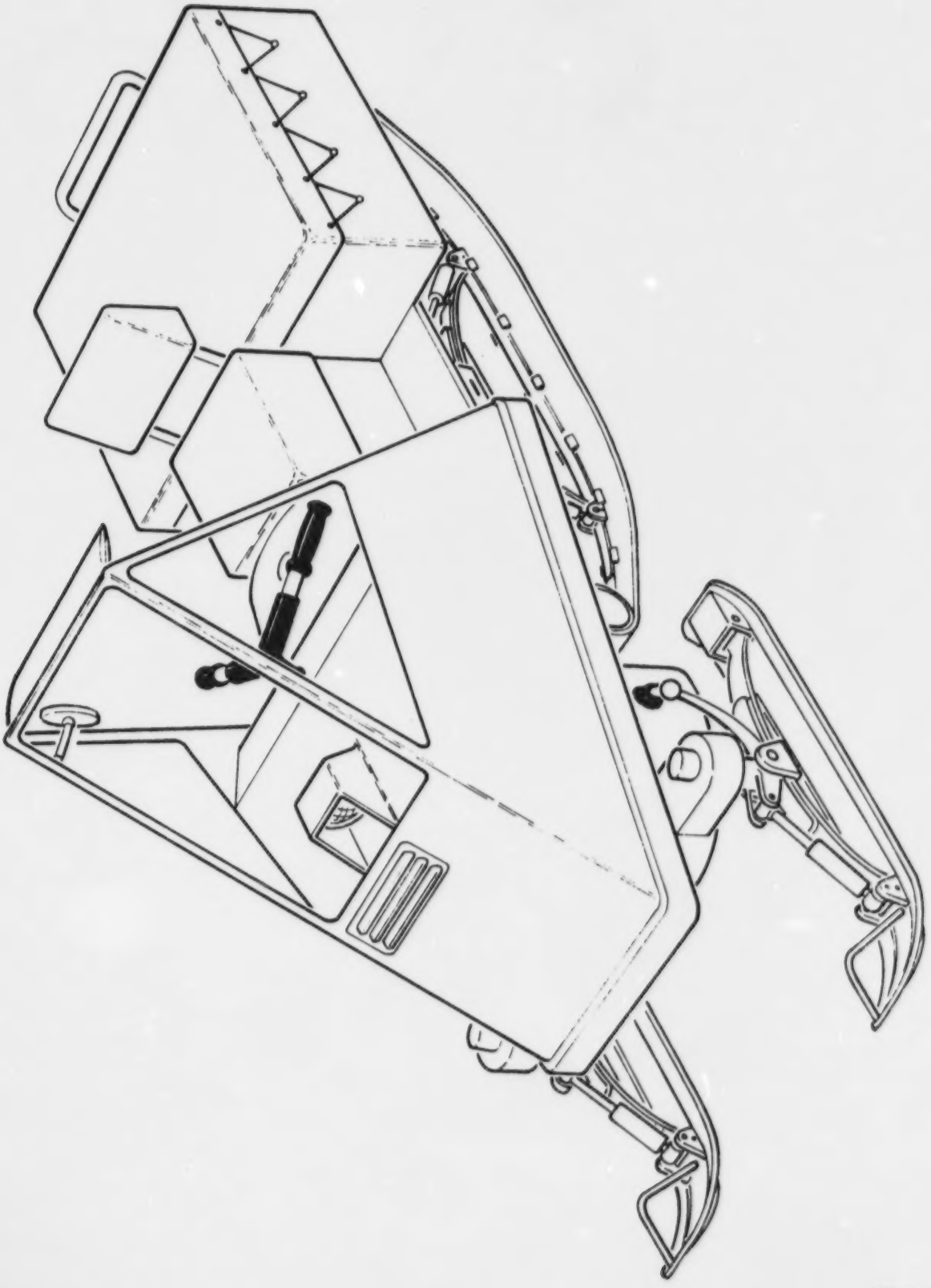
UTILITY SNOWMOBILE - TDC CONCEPT

The design illustrated is an attempt to fulfill the Arctic snowmobile kit concept while moving away from the low-slung "racy" designs of current snowmobiles. The design is characterized by a flat-bed to which all components are attached. The flat bed is a plywood sheet, preferably reinforced and protected by epoxy-fiberglass, and strengthened by a tunnel structure supporting the tracks and forward skis.

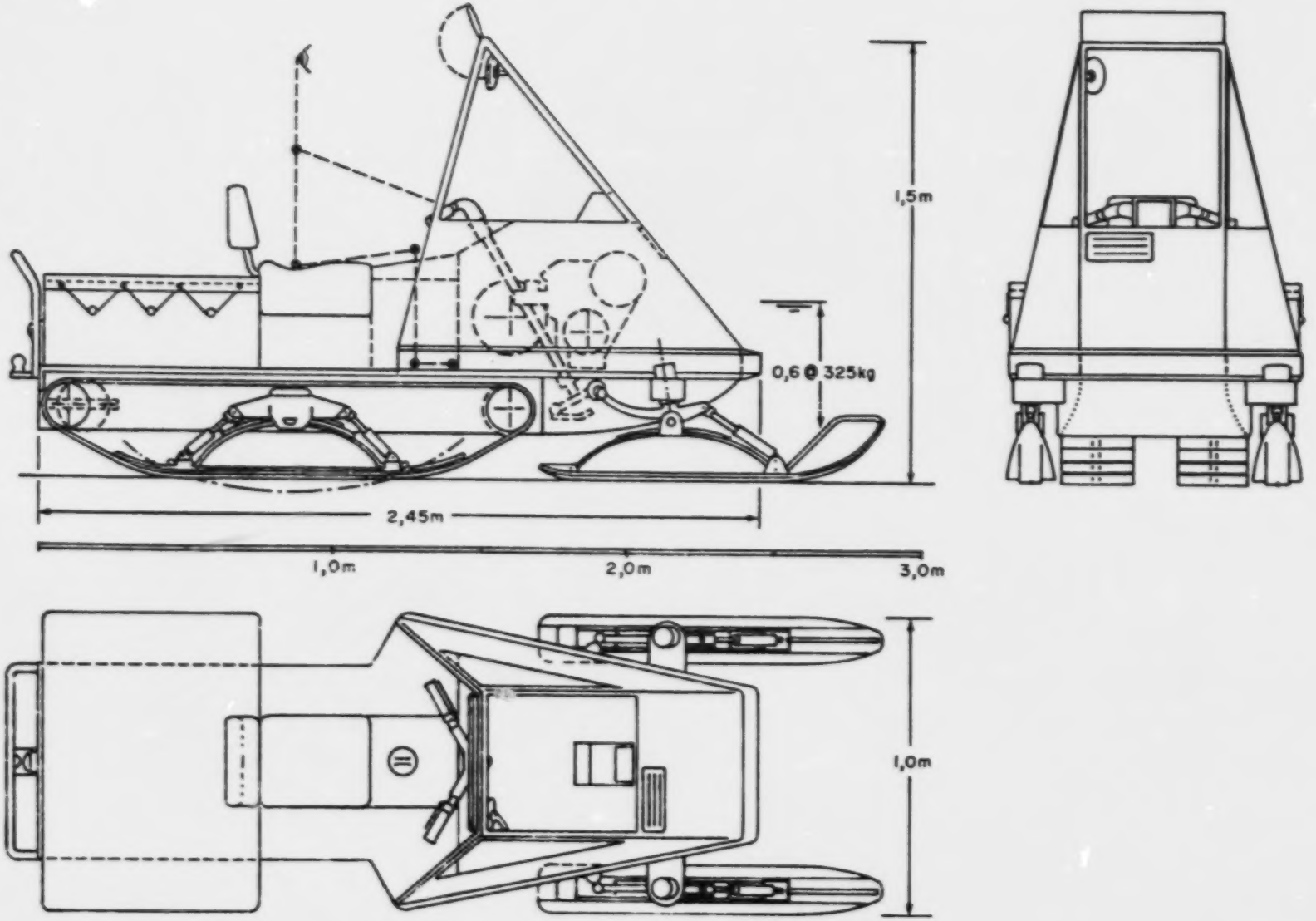
Most of the components, such as the cargo box and cowling could be fabricated in local shops. The volumes taken up by the cowling and by the box are sufficient to provide short-term floatation up to a 325 kg (700 lb) displacement. Maintenance is eased as there is no need for compaction of the electrical circuitry and other systems.

The centre of gravity is of course higher than in low-slung design: this is counterbalanced by the wide-stance of the skis and tracks; furthermore, as a utility machine it has no need for high speed cornering ability.

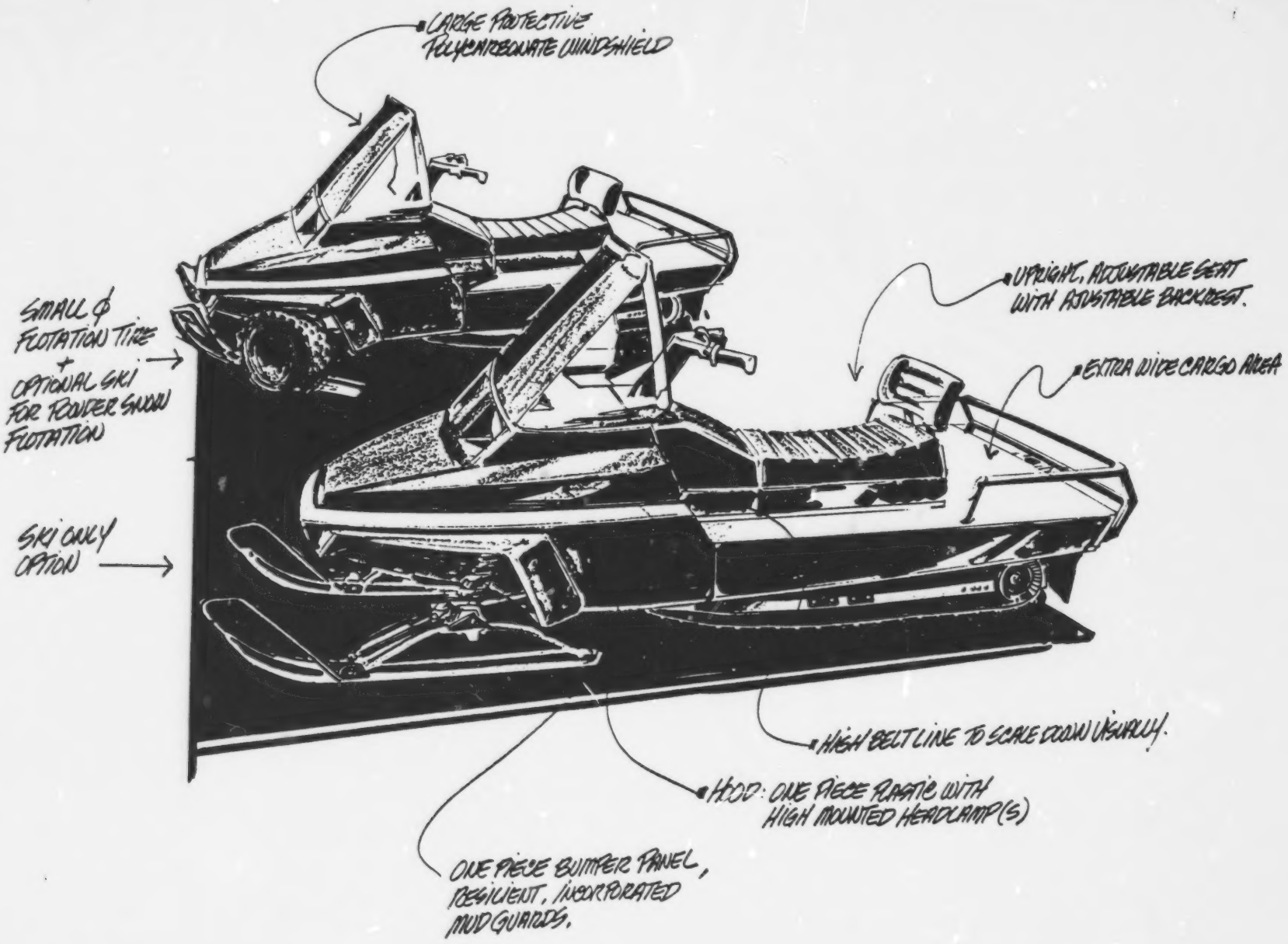
The design illustrated here is based on the twin-track "Best-Test" design, but with a Yamaha-type slider and with the tensionning sprockets attached to the frame, for minimum unsprung weight. It is of course quite feasible, with the flat-bed concept, to use a single track arrangement with wheel support, as well as modifying the vehicle plan form to suit the owner's needs.



TDC 2



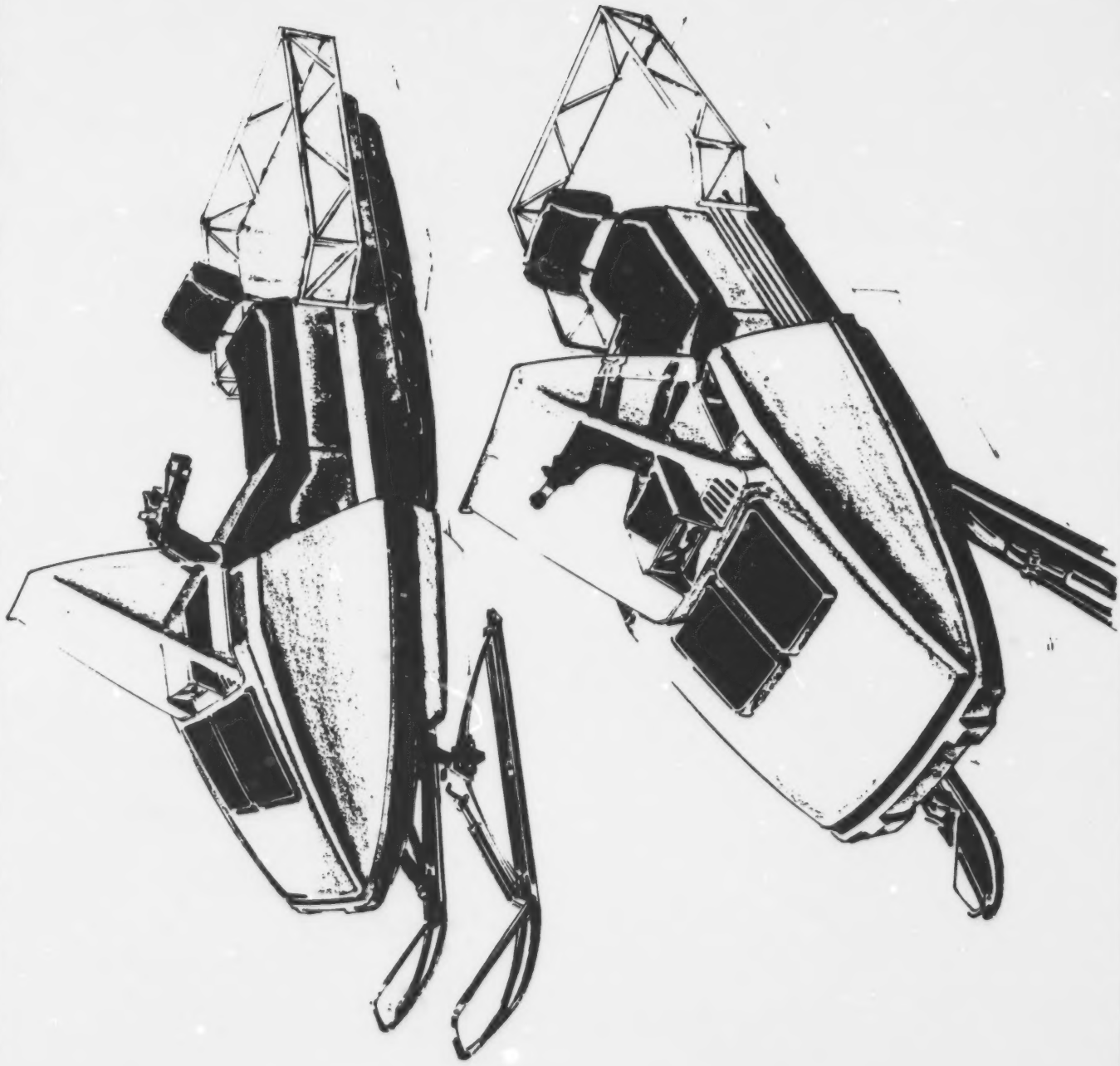
TDC 3


LARGE PROTECTIVE POLYCARBONATE WINDSHIELD
SMALL Ø FLOTATION TIRE + OPTIONAL SKI FOR POWDER SNOW FLOTATION
SKI ONLY OPTION
UPRIGHT, ADJUSTABLE SEAT WITH ADJUSTABLE BACKREST.
EXTRA WIDE CARGO AREA
HIGH BELT LINE TO SCALE DOWN VISUALLY.
HOOD: ONE PIECE PLASTIC WITH HIGH MOUNTED HEADLAMP(S)
ONE PIECE BUMPER PANEL, RESILIENT, INCORPORATED MUD GUARDS.

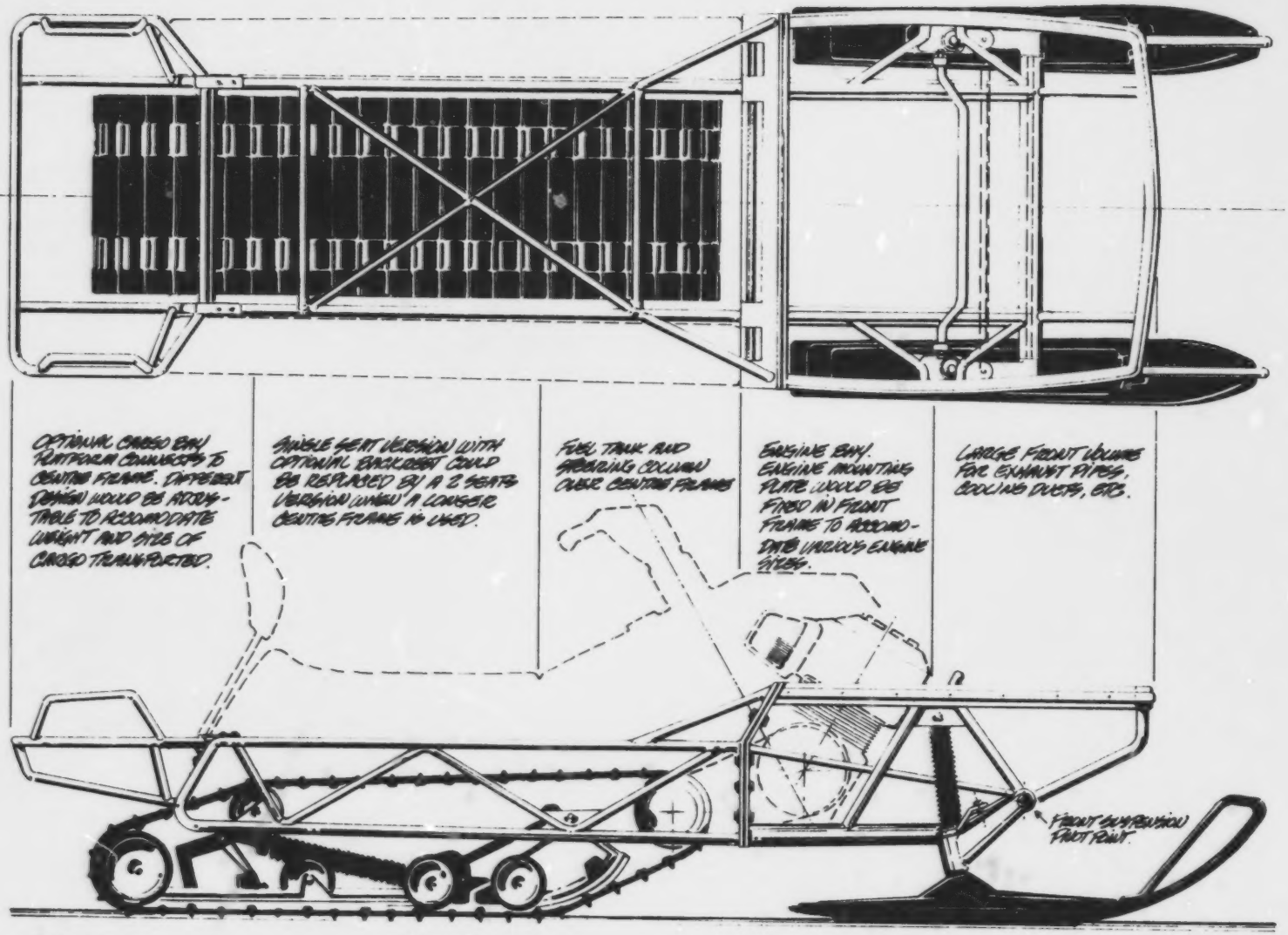
GSM 1

ARCTIC SNOWMOBILES

TIRES + SKI KIT COMBINATION
PRELIMINARY PROPOSAL — SKETCH.
M. SWIFT. DEC. 1983.



GSM 2


OPTIONAL CARGO BAY PLATFORM CONNECTS TO CENTRE FRAME. DIFFERENT LENGTH WOULD BE ADJUSTABLE TO ACCOMODATE WEIGHT AND SIZE OF CARGO TRANSPORTED.
SINGLE SEAT VERSION WITH OPTIONAL BACKREST COULD BE REPLACED BY A 2 SEATS VERSION WHEN A LONGER CENTRE FRAME IS USED.
FUEL TANK AND STEERING COLUMN CLOSE CENTRE FRAME
ENGINE BAY. ENGINE MOUNTING PLATE WOULD BE FIXED IN FRONT FRAME TO ACCOMODATE VARIOUS ENGINE SIZES.
LARGE FRONT VOLUME FOR EXHAUST PIPES, COOLING DUCTS, ETC.
FRONT SUSPENSION FRONT POINT.

REAR FRAME

DESIGNED TO ACCOMODATE CARGO NEEDS.

CENTRE FRAME

SPACE FRAME, TUBULAR CHASSIS COULD BE MADE IN DIFFERENT LENGHTS TO ACCOMODATE LONGER TRACKS. CHASSIS PROVIDES A LOW CENTER OF GRAVITY FOR INCREASED STABILITY AND REDUCED WEIGHT WITHOUT SACRIFICING STRENGTH.

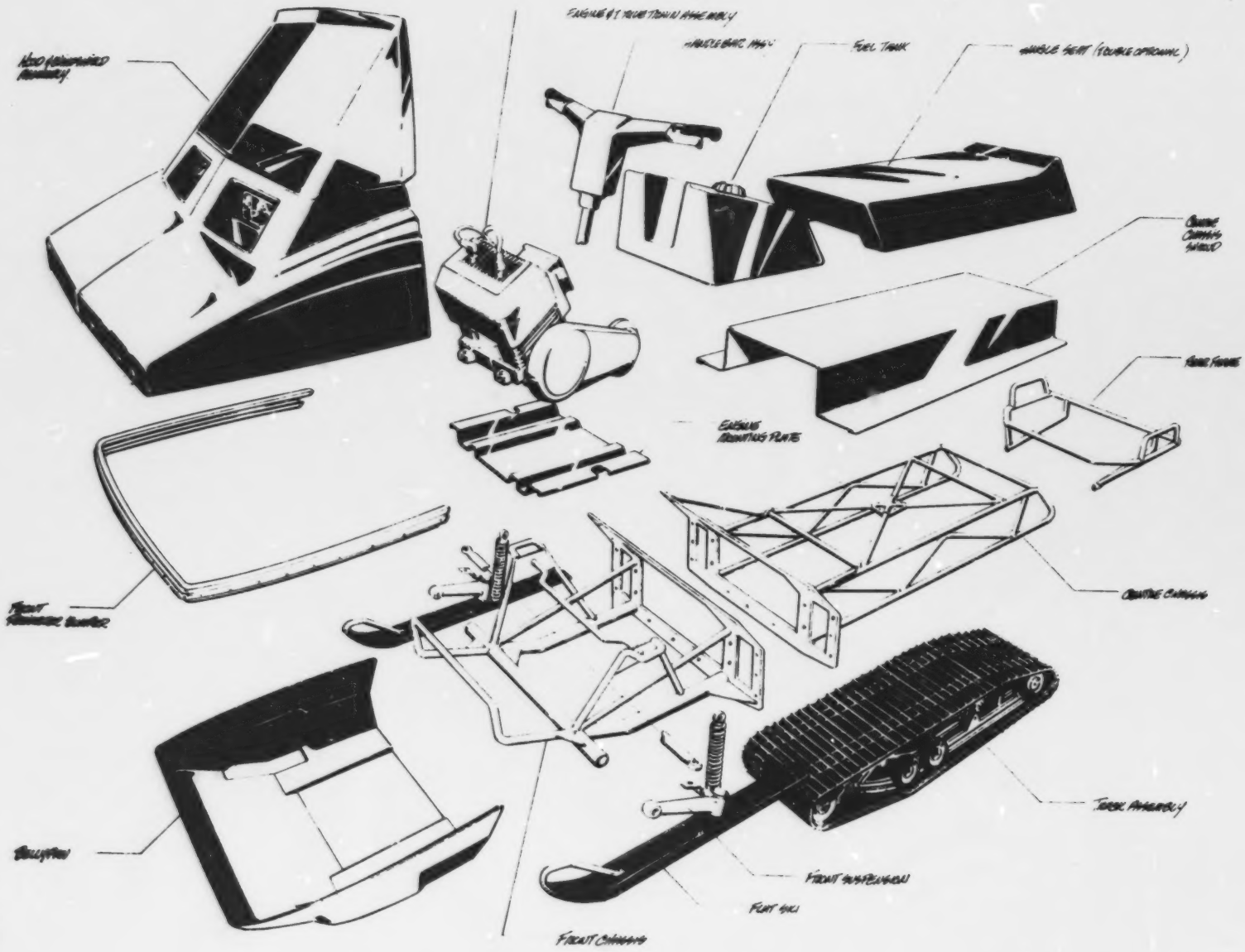
FRONT FRAME

SPACE FRAME, TUBULAR CHASSIS WOULD BE MADE TO MEASURE TO ACCOMODATE DIFFERENT ENGINES.

GSM 3

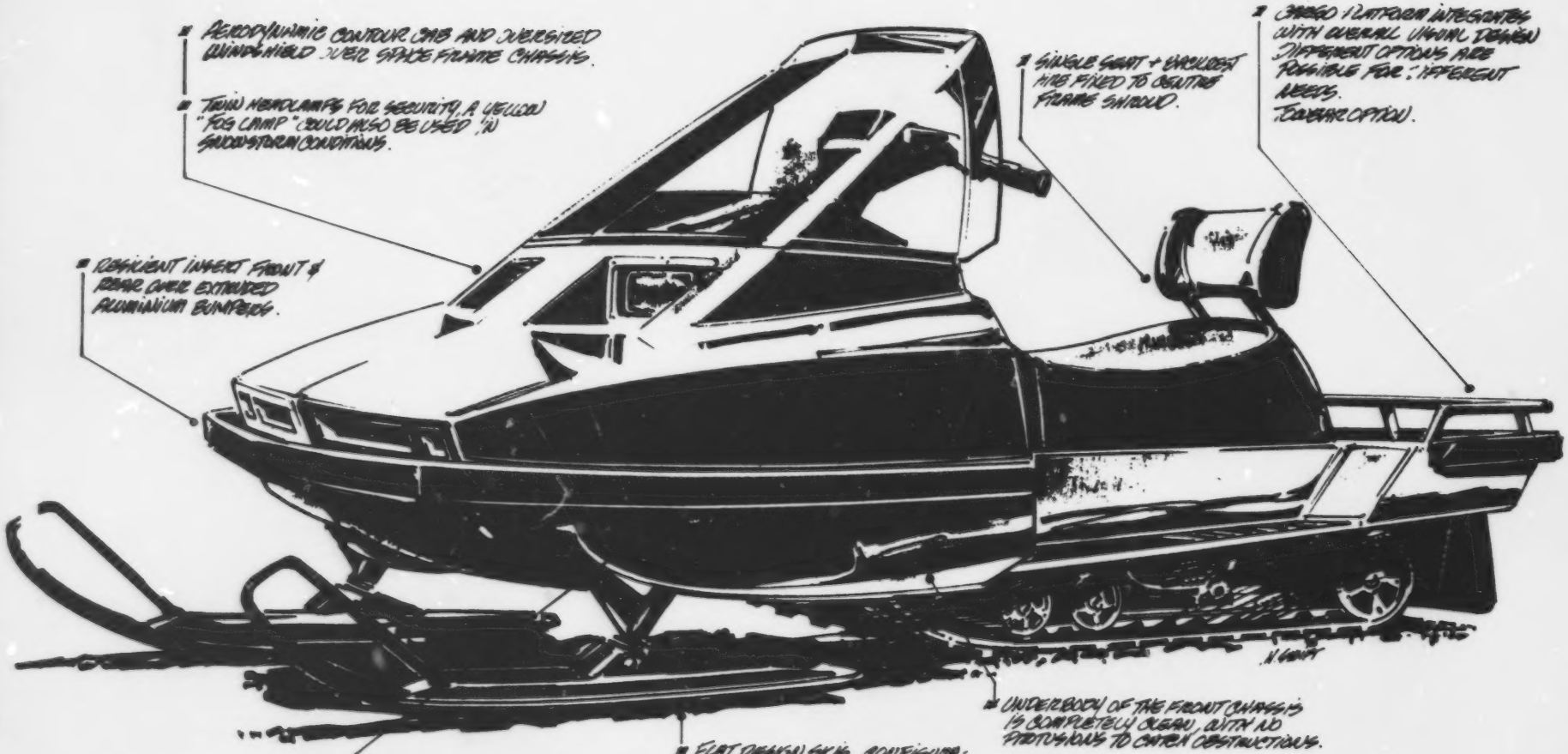
ARTIC SNOWMOBILE

FRAME CONCEPT



ARTIC SNOWMOBILE

MAJOR COMPONENTS


AERODYNAMIC CONTOUR CAB AND OVERSIZED WINDSHIELD OVER SPACE FRAME CHASSIS.
TWIN HEADLAMPS FOR SECURITY. A YELLOW "FOG LAMP" COULD ALSO BE USED IN SNOW STORM CONDITIONS.
RESILIENT INSERT FRONT & REAR OVER EXTRUDED ALUMINIUM BUMPERS.
SINGLE SEAT + UNCLUTCH ARE FIXED TO CENTRE FRAME SHROUD.
CARGO PLATFORM INTEGRATED WITH OVERALL UNIVAL DESIGN. DIFFERENT OPTIONS ARE POSSIBLE FOR DIFFERENT NEEDS. TOWBAR OPTION.
UNDERBODY OF THE FRONT CHASSIS IS COMPLETELY CLEAN, WITH NO PROTUSIONS TO CATCH OBSTRUCTIONS. REDUCED DRAG IN DEEP SNOW.
FLAT DIAGON SKIS, CONFIGURATION AND DUAL MOVEMENT, BACK-AND-UP SKI ACTION GIVE FLATTER TURNING, WITH LESS SNOWMOBILE TIP.
COMPLETELY FINISHED APPEARANCE AND SHOCK ABSORBING PROTECTION PROVIDED BY FLEXIBLE RUBBER STEERING COVERS ON THE FRONT CORNERS OF THE BELLY PAN.

GSM 5

ARTIC SNOWMOBILE

BODY COMPONENTS

Appendix C

SPECIFICATION: CUYUNA UL11-02 ENGINE PACKAGE

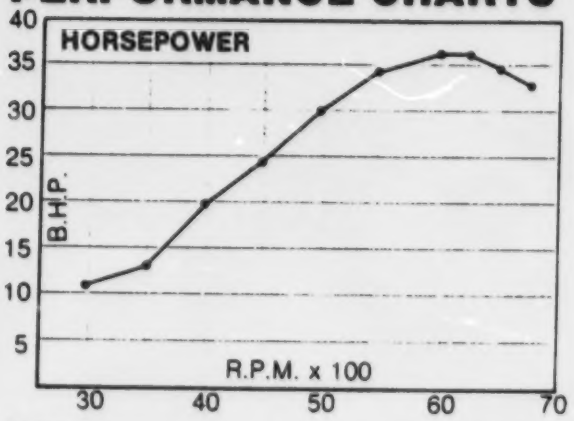
CUYUNA ULII

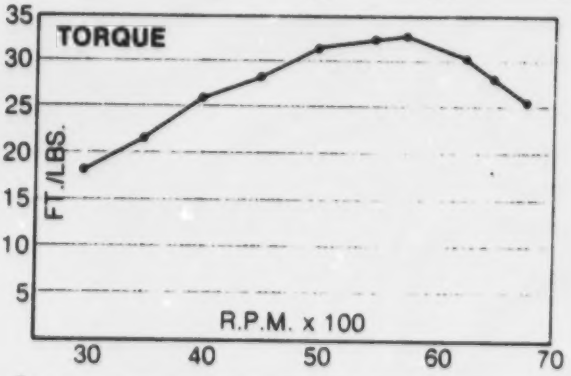
SPECIFICATIONS
(STANDARD PRODUCTION ENGINE)

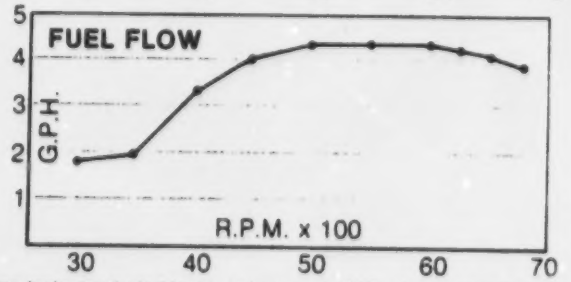
Model	ULII-02
Number of Cylinders	2
Bore	2.658"
Stroke	2.362"
Displacement	428cc
Compression Ratio	12.5:1
Brake HP/rpm	35 HP 6250 RPM
Base Mounting Hole Thread	7/16" - 14 UNC
Cylinder	Aluminum with Cast Iron Sleeve
Connecting Rod Bearing Upper	Needle
Connecting Rod Bearing Lower	Needle
Connecting Rod Material	Forged Steel
Main Bearings	Heavy Duty Ball Bearings, Dual Row Bearing, PTO End
Number of Main Bearings	4
Ignition	Capacitor Discharge (CDI)
Lighting Coil	12 Volt, 150 Watt AC Output
Ignition Setting Before TDC	18 Degrees .070"-.078"
Spark Plug Thread	14 x 1.25mm. 3/4" Reach
Gap	.016" to .020"
Type	Champion N3C or NGK BR8ES
Cooling	Axial Flow Fan
Rotation	Counter-Clockwise Viewed From PTO End
Fuel-Oil Mixture	40:1 (1 pt. to 5 gal.)
Lubrication	Regular Grade Gasoline & CUYUNA 2 Cycle Engine Oil
Starter	Rewind Type, Standard
Weight	58 lbs.

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE.

PERFORMANCE CHARTS







Engine tests conducted in accordance with SAE J607 using standard Cuyuna exhaust and carburetion. Graphs indicate a composite of part and full throttle operation and are used for illustrative purposes.

ACCESSORIES

Cuyuna oil
Electric start (R Model-Twin)
Reverse flow fan
Carburetion and exhaust system
Regulator
Regulator/Rectifier

FLY WITH THE LEADER

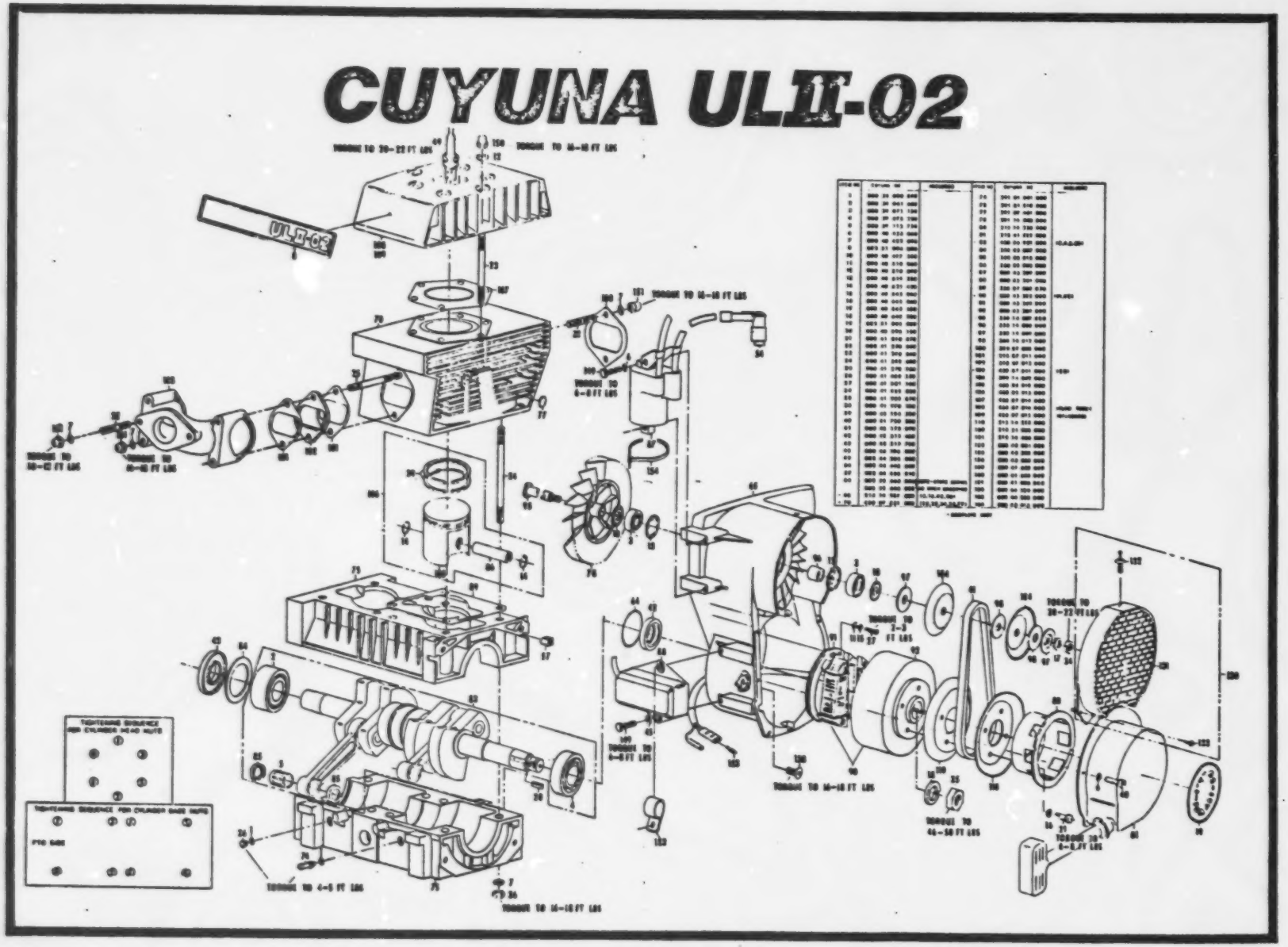
CUYUNA

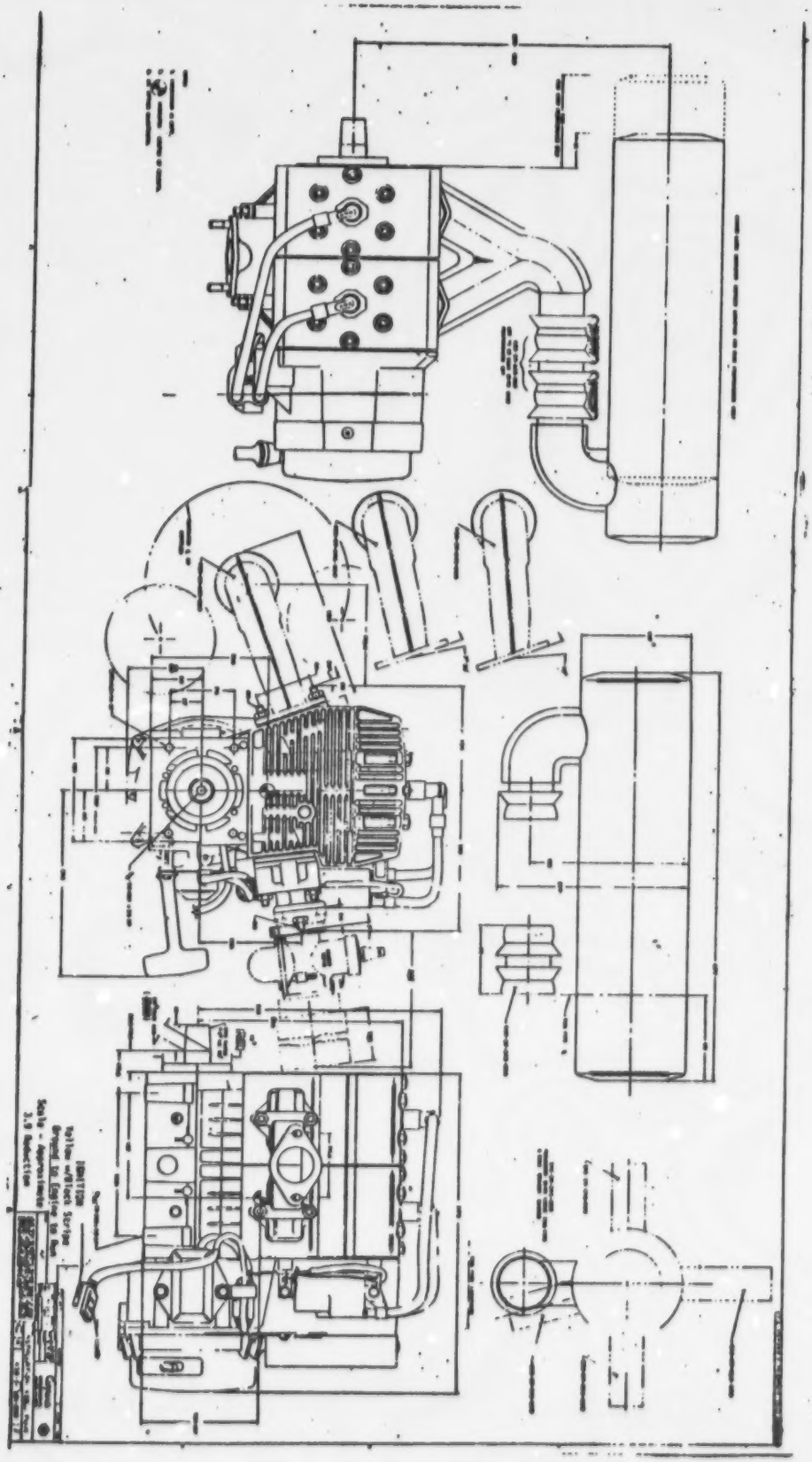
MANUFACTURED IN THE U.S.A.

CUYUNA ENGINE COMPANY, BOX 116, CROSBY, MN 56441

January 1, 1983

CUYUNA ULII-02

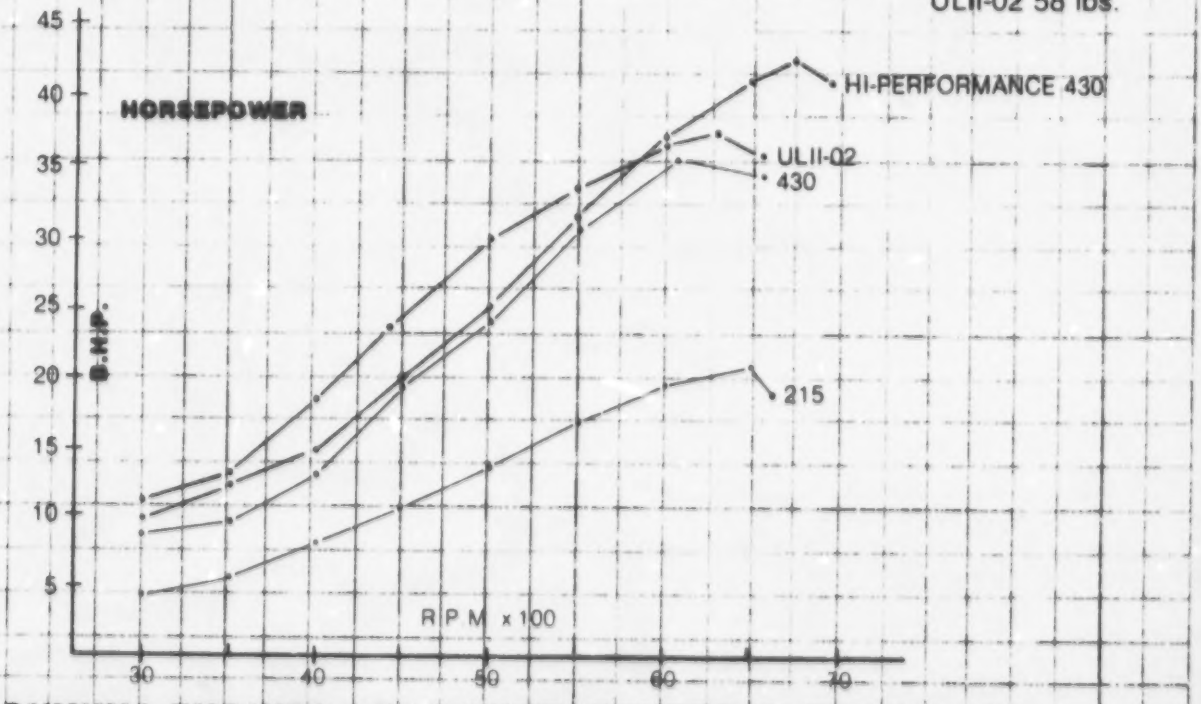




Cuyuna Engines

SPECIFICATIONS - AIR COOLED ENGINES

TYPE	SINGLE CYLINDER	TWIN CYLINDER
Model	215R	430R & ULII-02
Bore	2.658"	2.658"
Stroke	2.362"	2.362"
Displacement	214cc	428cc
Compression Ratio	12.5:1	12.5:1
Brake HP/rpm	20HP 6000/6500RPM	35HP 6200RPM
Base Mounting Hole Thread	7/16" - 14 UNC	
Cylinder	Aluminum with Cast Iron Sleeve	
Connecting Rod Bearing Upper	Needle	
Connecting Rod Bearing Lower	Needle	
Connecting Rod Material	Forged Steel	
Main Bearings	Heavy Duty Ball Bearings, Dual Row Bearing, RTO End	
Number of Main Bearings	2	4
Ignition	Capacitor Discharge (CDI)	
lighting Coil	12 Volt, 150 Watt AC Output	
Ignition Setting Before TDC	18 Degrees .070" - .078"	
Spark Plug Thread	14 x 1.25mm. ¾" Reach	
Gap	.016" to .020"	
Type	Champion N3C or NGK BR8ES	
Cooling	Axial Flow Fan	
Rotation	Counter-Clockwise Viewed From RTO End	
Fuel-Oil Mixture	40:1 (1 pt. to 5 gal.)	
Lubrication	Regular Grade Gasoline & CUYUNA 2 Cycle Engine Oil	
Starter	Rewind Type, Standard	
Weight R Model	42 lbs.	430R 65 lbs. ULII-02 58 lbs.



CUYUNA ENGINES ARE MANUFACTURED IN THE U.S. BY CUYUNA ENGINE COMPANY, BOX 116, CROSBY, MN 56441

CUYUNA ENGINE COMPANY

OEM PRICE LIST - EFFECTIVE JANUARY 1, 1983

ENGINE PACKAGE INCLUDING CARB., FUEL PUMP & EXHAUST	OEM PRICING LEVELS			SUGGESTED DEALER	SUGGESTED RETAIL
	LEVEL I (OVER 1,000)	LEVEL II (301-1,000)	LEVEL III (26 - 300)		
STANDARD 215R 20 BHP	$ 440.00	$ 460.00	$ 480.00	$ 520.00	$ 710.00
STANDARD 430R 35 BHP	550.00	570.00	590.00	630.00	860.00
ULII-02 35 BHP	560.00	580.00	600.00	640.00	870.00
HI-PERFORMANCE 430R 43 BHP	600.00	620.00	640.00	690.00	925.00
OPTIONS:					
"D" OPTION	25.00	25.00	30.00	35.00	45.00
"F" OPTION	15.00	15.00	15.00	20.00	30.00
EXHAUST MOUNTING KIT	15.00	15.00	15.00	20.00	28.00
ELECTRIC START	90.00	90.00	100.00	110.00	135.00

EXPLANATION OF ENGINE CONFIGURATION:

STD 215R OR 430R PACKAGE - Basic engine includes recoil starter, CDI ignition with 150 watt alternator, intake manifold, inlet air screen, Mikuni carburetor, fuel pump, air cleaner, and complete exhaust system, but without mounting.

ULII-02 PACKAGE - This lightweight 430 CC is distinguished by a rich black coat of heat resistant paint and highlighted by red and silver trim. Also includes carburetor and exhaust package. (Available March, 1983)

HI-PERFORMANCE 430R - Factory installed high performance kit for the standard 430 CC twin. Kit includes dual Mikuni carbs and produces 43 brake horsepower (BHP) and must be propped at 7000 RPM. Standard warranty applies when installed on a new engine at the factory. Not available on the ULII-02.

"D" OPTION - Available as an addition on all engines and has an additional crankshaft bearing on the PTO end of the crankshaft. This option must be used when mounting the propeller directly on the PTO end of the crankshaft. Electric Start cannot be used on a "D" option engine.

"F" OPTION - Available on all engines. (Reverse Flow Fan) - This option is a replacement of the standard fan with a cooling fan that pulls the air from the PTO end of the engine to the recoil end. This option must be used when mounting the engine with the PTO end facing the direction of travel.

ELECTRIC START - Available for the Standard 430R, ULII-02 and the Hi-Performance 430R. Not available for the single cylinder 215R. Electric Start kit is sold without battery.

CARBURETOR/EXHAUST KIT - May be purchased separately for $100.00. Includes a properly calibrated Mikuni carburetor, fuel pump, air cleaner and complete exhaust system, but without mounting.

HI-PERFORMANCE KIT - May be purchased separately for $150.00. Includes dual Mikuni carburetors and complete exhaust system. Standard engine warranty does not apply unless installed on a new engine at factory.

EXHAUST MOUNTING KIT - Used to mount Cuyuna exhaust system to engine. Aluminum mounting angles utilize the cylinder head studs for mounting. OEM price - $15.00

TERMS AND CONDITIONS:

- Engines purchased from January 1, 1983 through December 31, 1983 are included in OEM pricing level program.
- Engine Package prices are reduced as you move into new pricing level. For example, your first 300 Standard 430R engines are $590.00; starting with the 301 engine your price drops to $570.00; at 1001 it drops to $550.00 per engine.
- Engines purchased without carb and exhaust package - subtract $100.00 from pricing levels. Subtract $150.00 for Hi-Performance engine.
- All prices are F.O.B. Crosby, Minnesota.
- Unless prior arrangements have been made with Cuyuna, terms of sale are cash in advance or equivalent, or Irrevocable Letter of Credit.
- Prices subject to change without notice.
- Warranty - A 90 day after first use limited warranty will apply. See Owners Manual or Cuyuna's Warranty Policy and Procedures for details.

COMPARE THE "CUYUNA PROGRAM" TO THE COMPETITION:

- Proven engines. There are more Cuyuna engines in use in ultralights than any other engine in the industry.
- ULII-02. This lightweight fuel efficient engine has been designed solely for ultralight use.
- CDI. The capacitor discharge ignition is standard on Cuyuna engines.
- Engine options. Cuyuna engines may be ordered completely machined, drilled and tapped for mounting a reduction drive unit directly on the engine. Other options available.
- Appearance package. The new ULII-02 is distinguished by a rich black coat of heat resistant paint and highlighted by red and silver trim.
- Factory training schools. Free two day factory training schools for your personnel and your dealers.
- Technical assistance. Factory engineers at Crosby, Minnesota are available to assist you in your installation and application of Cuyuna engines.
- Customer Service hotline. Cuyuna provides a Customer Service Department with personnel to assist your dealers and retail customers after the sale.
- Parts availability. Parts are readily available from the factory; Crosby, Minnesota, U.S.A.
- Response time. Prompt order processing and shipment of engines and parts. Parts orders shipped within 24 hours of receipt of order.
- Co-op advertising. Cuyuna offers a Co-op Advertising Program enabling you to stretch your advertising dollars.
- Factory advertising. Cuyuna promotes your engine and the sport of ultralight flying.
- Active PUMA member. Cuyuna commits time and money to working for the good of the industry.
- Commitment to sport. Cuyuna is an ultralight engine company. Our personnel fly ultralights as part of our continuous research and development to improve the Cuyuna engine.

Only Cuyuna offers you a "total OEM program". Compare the value of what Cuyuna has to offer you with what the competition offers. Cuyuna does not just offer reasonable prices, we offer much more. After you have examined the competition, we think you will agree - - it pays to fly with the leader!

CUYUNA Engines

June, 1983

Cuyuna Engine Company operates out of a modern 187,500 square foot facility in Crosby, Minnesota, about 120 miles northwest of the Minneapolis-St. Paul area. Cuyuna is a privately owned company which manufactures lightweight, two cycle engines in the 20 to 50 horsepower range, provides engineering and product development services and manufactures the Wetbike recreational water vehicle.

Cuyuna's engines primarily are used by the ultralight aircraft industry. Cuyuna purchases raw materials, such as forgings and castings, and completely machines these components and assembles the engines. Cuyuna's capacity is about 25,000 one or two cylinder engines per year. Each engine is individually run and tested prior to shipment. Engine sales are currently running at the rate of $2,500,000 to $3,000,000 annually. Cuyuna is the only high volume, domestic manufacturer of two cycle, air cooled engines in the 20 to 50 horsepower category.

During the past three years, Cuyuna has performed a number of design and development projects for third parties, primarily related to engines. Cuyuna has four 85 BHP dynamommeters and a vast array of other specialized engine test equipment as well as highly skilled technical personnel. Pattern makers, foundries and other such support facilities are readily available in the area. Cuyuna believes it is unique as a manufacturer of engines offering their design and prototype services to third parties. During the current year about $700,000 in income will be generated from these services.

The Wetbike product line is owned by a third party, but Cuyuna has complete manufacturing responsibility for the vehicle. Included in the manufacturing processes are Resin Injection Molding (RIM), Resin Transfer Method (RTM), and Cold Press Forming of all fiberglass components. Approximately $1,500,000 (dealer cost) worth of Wetbikes will be manufactured this year.

We invite your inquiry into any areas in which we have expertise. Please call me if I can be of assistance.

Best regards,

CUYUNA ENGINE COMPANY

Roger P. Worth
President

RPW:jmr

CUYUNA ENGINE COMPANY
P.O. BOX 116, CROSBY, MN 56441
(218) 546-8313

Appendix D

THE HISTORY OF SNOWMOBILE TRACK DEVELOPMENT

ARCTIC SNOWMOBILE PROJECT

A review of the history and development of recreational snowmobile tracks.

With respect to the present project, there has been considerable comment concerning our decision to utilize two small tracks, spaced apart as opposed to one large track. Hence, it would appear appropriate to review the history of track development and some of the reasoning behind our selection.

To begin, one must remember that the track system is perhaps the single most important element of the vehicle in terms of cost, tooling, performance, top speed, handling, braking to mention just a few points. Hence, any track is something of a compromise since generally each model of snowmobile has a specific orientation.

A tour through the Bombardier snowmobile museum in Valcourt, indicates the degree of importance the track played in snowmobile development. In fact, the endless rubber track concept as patented by J. Armand Bombardier along with the Arctic Cat type slide suspension may be considered as the two major elements of the industry.

Both were the subject of patents and for over a decade, the industry was literally split between the Bombardier rubber track and bogie wheel suspension concept and the Arctic Cat slide suspension and exterior grouser element fabric track.

To fully explain the advantages and disadvantages of these tracks would require several volumes. In short, the Bombardier system was superior in deep snow and marginal ground, and was perhaps cheaper over the lifetime of the vehicle. The Arctic Cat system offered smooth riding and high speed on hard surfaces and limited snow cover such as experienced in the central and mid-west.

It should be noted however, that the first recreational snowmobile built by J. Armand Bombardier had two tracks and one could say that the Alpine and Elite models follow in its tracks.

.../2

Until Circa 1972, these concepts dominated the industry. Two groups of machines evolved, related almost directly to the geographic conditions. Track width varied from 15" to 18". Top speed was not a dominant consideration and track drive system consumed some 30 to 40% of engine power.

Several events helped to change this pattern. The emphasis on vehicle use shifted to well-groomed trails. Bombardier introduced the Elan. The relative patents expired or were invalidated. New track and sprocket materials evolved including Kelvar fiber, and fiberglass rods. Snowmobile races evolved towards ice-covered, half mile oval tracks.

From 1973 to 1975, these factors changed the basic concept of the snowmobile. Suddenly, top speeds of 80 to 90 mph were the norm. Good ride and handling on hard packed, often icy (because of traffic) snowmobile trails became the keys to success.

The resulting research and development led to more free-wheeling tracks, generally 16 1/2 inches in width and sophisticated slide suspensions. Machines changed, with front mounted engines and wide, wide ski-stances becoming the norm.

However, the incredibly high tooling costs associated with tracks and frames and all the other related systems limited the manufacturer's ability to introduce new models and new systems. Particularly when the market was beginning to decline.

Many interesting concepts evolved during this period only to disappear as company after company closed shop. One such concept was the pararail suspension, a cross between bogie and slide. Another was the twin track concept of the Raider.

The latter created shock waves within the industry because of its revolutionary Formula 1 type styling and the use of two small rearward mounted tracks. In fact Bombardier, Honda and perhaps others prepared and tested full scale versions of similar concepts.

However, while these machines performed incredibly well, they were relatively expensive and unfortunately the seating position was such that one could not "bail out" in case of trouble which resulted in a sense of claustrophia for many people. Hence, the concept was abandoned for general use.

.../3

The performance of these machines, however, was not lost on the racing community. Long before Gilles Villeneuve won his first Formula I race, he was dominating the racing circuit on twin-tracked formula type racing machines, first for Alouette, then for Bombardier. It is difficult to adequately describe the performance of these machines, but it is perhaps sufficient to say that they can be driven nimbly around an ice-covered half mile oval at 100 mph.

Hence, for the purposes of the present project, we are effectively crossing this technology with that of the first snowmobile and the Alpine and Elite which followed. The intent is to combine the best of both systems.

It should also be noted that some very specific criteria have been setforth for the vehicle. This is a flexible vehicle but it has a dedicated purpose. Also, one must recall that to some extent, we are not bound by the same tooling constraints as a high volume manufacturer.

Two 8" wide tracks by 139" long provide more floatation then on most existing snowmobiles. By spacing the tracks apart, we gain the stability and independent suspension action of the Raider concept. Since they will be narrow and light, they should permit a reasonable top speed without requiring a large engine since power loss in the drive system will be minimized. They should cost less and be less expensive to tool than regular tracks.

As concerns traction, in deep snow the vehicle should be superior to most existing single tracked vehicles but probably not as good as an Alpine. However, while an Alpine may be good in terms of straight ahead pulling power, it often becomes struck because of poor manoeuvrability (one ski) and its great weight. Despite the reverse, it cannot climb out of a "hole" since the rear track profile is rounded and not sloped.

Also, experience has shown that in light snow or on very slippery surfaces, the Alpine's traction is greatly reduced. It is believed that this is because its track surface is so great it has no bite. Somewhat like a lightweight sports car with large, wide tires that will simply spin its wheels on ice or in slush.

.../4

This is a prime consideration since the information collected indicates that 60-70% of the time, the vehicles in the North are operating in anything but deep snow. It is thus anticipated that on hard packed or in marginal snow or mud the smaller tracks will be superior.

In deep snow, it is expected that the improved manoeuvrability of the vehicle will in great measure compensate for any loss in straight away traction.

A snowmobile like snow itself has a complex structure and many factors influence overall performance. The Arctic Snowmobile must meet some demanding requirements. In fact, no current production snowmobile could meet the parameters we have chosen. Hence, we are adopting a slightly different approach. However, the technology has been well proven and the principle itself dates back to the very origins of the snowmobile.

George-Allen Gowing, eng.,
President

BEST TEST Inc.

23.1.84

Appendix E

CALCULATIONS AND EXPERIMENTS RELATED TO VEHICLE FLOTATION

– ARCTIC SNOWMOBILE PROJECT –

Vehicle flotation

During the course of the project, it has become apparent that snowmobiles are frequently operated by Northern users in areas where open water exists. There is a clear and present danger. Hence, one of the basic design criteria fixed for the vehicle was that it floats.

We have discussed and analyzed various approaches to flotation. Two basic methods exist. The first is to seal the ''hull'' of the snowmobile like a boat (a la Finncat). The second is to build in flotation material. Naturally, there are variations to these basic approaches.

However, during our trip to Ft Chimo and George River, it became evident that the reality of the situation may in fact dictate the approach.

For instance, the terrain conditions were so severe that it is most unlikely that a ''sealed hull'' would remain undamaged for very long. In fact, one of the major complaints related to broken frames and bottom plates as well as fractured cabins, etc.

It also became apparent that the environment is such that recovery of the snowmobile will either take place immediately or not at all. Hence, the most important consideration is not to have the snowmobile float for hours but rather to float and if possible continue to operate so that the operator can reach safety.

In this context, one must consider that the snowmobile will often be carrying a load and/or pulling a heavily laden sled and that the border of the ice/water surface may not be smooth or flat. It was also mentioned that once the snowmobile has been exposed to salt water, it may not be worth recovering. The entire question of whether the snowmobile can be recovered by one person is in some doubt.

.../2

Hence, the following approach seems logical.

1> To provide that the snowmobile remain afloat in an upright position for at least 30 minutes.

2> To provide that the engine and track remain operative so that the vehicle has propulsion to reach the edge of the ice and to try to design the vehicle to facilitate removal from the water.

3> To provide means to secure the snowmobile to solid ground/ice to allow the operator to reach safety and to facilitate recovery of the vehicle.

4> To provide for means to rapidly separate snowmobile and sled should the situation warrant such action.

The initial investigation indicates it should be feasible to make the snowmobile float using a combination of flotation material and hull design without necessarily sealing the hull. It also appears that the snowmobile's attitude can be maintained reasonably levelled.

However, at the prototype stage, it will be important to investigate the reaction of the snowmobile as it enters the water in various modes and the effect that pulling a sled may have upon the entire process. It will also be important to consider the facility with which the occupant can escape to safe ground.

Some of this work could be carried out in summer, however, it would also be desirable to conduct some tests in a shallow lake or basin in winter with real ice conditions.

George A. Gowing, eng.,
President
BEST TEST Inc.

May 9, 1984

cc: Peter Poole (23/05/84)

SNOWMOBILE FLOTATION TEST

Prepared for: Mr. Peter Poole

by: Frank Gabbianelli, jr. eng.,
Bureau d'Etudes & Systèmes
Techniques Test Inc. (BEST TEST)
971, Labelle, suite 205
Blainville, Quebec J7C 2L8

Date: May 22nd, 1984

SNOWMOBILE FLOTATION TEST

The aim of this test was to:

1) evaluate the flotation characteristics of existing snowmobiles

2) verify the theoretical flotation calculation conducted for the proposed prototype.

Procedure:

To demonstrate the flotation characteristics of a snowmobile, the test was separated into two phases.

In the first phase of the test, the buoyancy forces of an Arctic Cat snowmobile were measured while the vehicle was being immersed to specified depths. The force measurements were recorded with the aid of a load cell and force indicator located on the cable supporting the vehicle.

This test provides a good indication of the quantity of flotation material required to maintain the vehicle afloat at a specified depth.

The second phase of the test was performed to determine the total flotation time of the Arctic Cat snowmobile. The results were obtained by monitoring the time required for the vehicle to be completely submerged. This procedure provides a good indication of the rate at which water enters the vehicle components.

Results:

FLOTATION TEST

Performed on May 11, 1984

TABLE #1 Buoyancy forces

Portion submerged	Vehicle's weight (kg)
0	208.1
1/4	134.8
1/2	81.3
3/4	74.7
Fully	71.3

TABLE #2 Flotation time

Weight of vehicle (kg)		Time (sec)
Start	End	
208.15	25.8	0

NOTE: Vehicle was submerged just below water level line.

Conclusion

During the flotation test, it was observed that when the snowmobile was completely submerged, the tension in the support cable was approximately 22 kg, which indicates that the vehicle is almost at equilibrium. Therefore, if the vehicle was to be fitted with 0.127 m^3 (4.5 ft^3) of flotation material, it would enable it to float 3/4 submerged while supporting 67.9 kg (150 lb) person. This result is approximately the same as the result obtained during the flotation calculations performed on the proposed prototype.

The results of this test also illustrate that the flotation time of this particular vehicle was extremely low. This was due to poorly located air inlets in the cabin and non-existant flotation material, which permit water to gain access to the cabin area and effectively reduce its potential flotation volume.

Therefore, a vehicle's flotation time can be greatly improved by strategically locating air inlets and sufficient flotation material in the cabin area.

After having completed the test program, it was noticed that the seat on the snowmobile had absorbed a large quantity of water, enough to increase its weight to approximately 45 lbs. Naturally, this does not aid the flotation capabilities of the vehicle. Hence, in the proposed prototype, it would seem important to fabricate the seat with a closed cell flotation material in order to take advantage of the seat's flotation potential.

Frank Gabbianelli, jr. eng.,
BEST TEST

— ARCTIC SNOWMOBILE PROJECT —

CENTER OF MASS AND FLOTATION CALCULATIONS

BY: Frank Gabbianelli,
Project Engineer

April 12, 1984.

cc: Peter Poole (23/05/84)

The following calculations are based on the following weights:

Track & suspension	50 lbs
Transmission	50 lbs
Engine	50 lbs
Cabin	50 lbs
Seat	15 lbs
Fuel tank	75 lbs
Skis	30 lbs
Shafts / sprokets	25 lbs
Tunnel	35 lbs
Bottom plate	15 lbs
Subframe	40 lbs
	435 lbs

CENTER OF MASS CALCULATIONS:

In the X direction (assuming a total weight of 807 lbs, which includes 150 lbs person, 150 lbs of cargo and 75 lbs of fuel).

Point of reference is the center of tank.

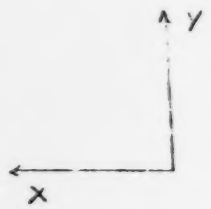
CM_x = 51'' x 10 lbs + 32'' x 25 lbs + 35'' x 150 lbs +
14'' x 20 lbs + '' x 15 lbs + 16'' x 150 lbs +
18'' x 50 lbs + '' x 75 lbs - 4'' x 12 lbs - 11'' x 50 lbs -
19'' x 50 lbs - 20'' x 40 lbs - 15'' x 25 lbs - 17'' x 15 lbs -
26'' x 50 lbs + 16'' x 35 lbs - 33'' x 30 lbs - 43'' x 5 lbs.

CM_x = (510 + 800 + 5250 + 280 + 210 + 2400 + 900 - 48 - 550 - 950
- 800 - 375 - 255 - 1300 + 560 - 990 - 215) lbs-in.

CM_x = 5427 lbs-in.

CM_x = 5427/ 807 lbs = 6.72 in

in the X direction (horizontal).



In the Y direction (assuming total weight of 807 lbs, which includes 150 lbs person, 150 lbs of cargo and 75 lbs of fuel).

Point of reference is the top of the tunnel.

CM_y = -50 lbs x 9'' + 50 lbs x 4'' + 50 lbs x 6''
+ 50 lbs x 7'' + 15 lbs x 11'' - 20 lbs x 4''
+ 75 lbs x 6'' + 150 lbs x 19'' + 150 lbs x 10''
+ 121lbs x 11'' - 30 lbs x 11''- 25 lbs x 2.5''
- 35 lbs x 1.5'' - 15 lbs x 2'' - 40 lbs x 1.5''

CM_y = (-450 + 200 + 300 + 350 + 165 - 80 + 450
+ 2850 + 1500 + 132 - 330 - 62.5 - 52.5
- 30 - 60) lbs-in.

CM_y = 4882 lbs-in. / 807 lbs = 6.05 ins.

above the tunnel

in the Y direction.

WEIGHT DISTRIBUTION:

Rear of vehicle:

CM = 44.28'' x 10 lbs + 25.28 x 25 + 28.28 x 150 + 7.28 x 20
+ 7.28 x 15 + 9.28 x 150 + 11.28 x 50 + 6.72 x 75
+ 9.28 x 35.

CM = 442.8 + 632 + 4242 + 145.6 + 109.2 + 1392 + 564 + 504 + 324.8.

CM = 8356.4 lbs-in.

Weight = 455 lbs

8356.4 lbs-in / 455 lbs = 18.37 ins.

Therefore a total rear weight of 455 lbs is located at 18.37 ins. from the center of mass.

Front of vehicle:

CM = -10.72'' x 12 - 17.72 x 50 - 25.72 x 50 - 26.72 x 40
-21.72 x 25 + 123.72 x 15 - 32.72 x 50 - 39.72 x 30
-49.72 x 5.

CM = (128.64 + 886 + 1286 + 1068.8 + 543 + 355.8 + 1636 + 1191.6 + 248.2)

CM = - 7344.04

Weight of front end = 352 lbs.

7344.04 lbs-in. / 352 lbs = 20.86 ins.

Therefore a total frontal weight of 352 lbs is located at 20.86 ins. from the center of mass.

FLOTATION CALCULATIONS:

Case I : Immediately after the snowmobile enters the water.

Assumptions:

1) assume that the water level inside the engine compartment is 7'' above the top of bottom plate.

2) assume that 3/4 of the cargo's volume displaces water for flotation.

   The weight of the cargo is 150 lbs.

3) assume that the cargo and the person remains on the vehicle to achieve flotation.

Weight of the snowmobile = $\rho g V$

where,

ρ = density of water

g = gravity (32.2 ft / sec^2)

V = volume of water displaced.

Weight of snowmobile is 807 lbs, this includes fuel, operator and 150 lbs of cargo.

807 lbs = 62.2 lbs/ft^3 x V

V = 12.97 ft^3

Therefore, this result would indicate that the water level will be located at 6.5 ins. from the top of the tunnel.

Since at that water level the volume displaced by the:

Tunnel	=	2.98 ft^3
Cabin	=	4.76 ft^3
Fuel tank and seat	=	1.35 ft^3
Cargo area	=	2.84 ft^3
Suspension	=	0.40 ft^3
Track	=	0.64 ft^3
TOTAL:		12.97 ft^3

The equilibrium position is:

Point of reference is 0.72'' to the right of the CM.

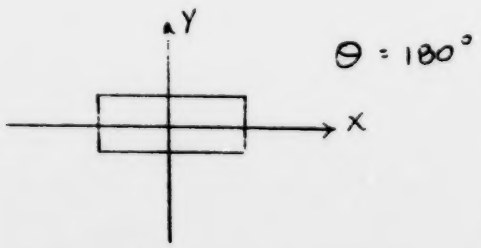
CM = 17.65'' (455 lbs) - 62.2 lbs/ft^3 (0.675 ft^3) (7.5 in)
- 62.2 lbs/ft^3 (2.32 ft^3) (21 in) - 62.2 lbs/ft^3 (2.84 ft^3) (29 in)
- 62.2 lbs/ft^3 (0.312 ft^3) (21 in) - 62.2 lbs/ft^3 (0.463 ft^3) (21 in)
- 21.61'' (352 lbs) + 62.2 lbs/ft^3 (0.66 ft^3) (8 in)
+ 62.2 lbs/ft^3 (4.76 ft^3) (28 in) + 62.2 lbs/ft^3 (0.675 ft^3) (7.5 in)
+ 62.2 lbs/ft^3 (0.088 ft^3) (6 in) + 62.2 lbs/ft^3 (0.137 ft^3) (8 in).

CM = (8030.75 - 314.89 - 3030.4 - 5122.8 - 407.5 - 604.8 - 7606.72
+ 328.4 + 8290.0 + 314.89 + 32.84 + 68.17) lbs-in.

CM = 22.04 lbs-in. (CW)

Angle at which the vehicle will float is (Θ)

Θ = 180°



FLOTATION CALCULATIONS:

Case II : When the snowmobile cabin has been filled with water.

Assumptions:

1) Assume that 1/2 of the cabin's volume is occupied with water and the remaining volume is occupied by the motor and the flotation material.

2) Assume that 3/4 of the cargo's volume displaces water, for flotation.

3) Assume that the person and the cargo remain on the vehicle.

Similarly, to achieve flotation:

Weight of the snowmobile = $\rho g V$

where,

ρ = density of water

g = gravity (32.2 ft / sec^2)

V = volume of water displaced.

Weight of snowmobile is 807 lbs, this includes full, operator and 150 lbs of cargo.

807 lbs = 62.2 lbs/ft^3 x V.

V = 12.97 ft^3

Therefore, this result would indicate that the water level will be located at 10.5 in. from the top of the tunnel.

Since, at that water level the

Volume displaced by the:

Tunnel	=	2.98 ft³
Cabin	=	2.16 ft³
Fuel tank & seat	=	2.19 ft³
Cargo area	=	4.60 ft³
Suspension	=	0.40 ft³
Track	=	0.64 ft³
TOTAL:		12.97 ft³

NOTE: if machine remains level

The equilibrium position is:

Point of reference is 0.72'' to the right of the center of mass.

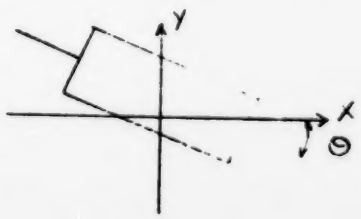
CM = 17.65'' (455 lbs) - 62.2 lbs/ft³ (2.32ft³) (21'')
- 62.2 lbs/ft³ (1.095 ft³) (7.5 in)
- 62.2 lbs/ft³ (4.60 ft³) (29 in)
- 62.2 lbs/ft³ (0.288 ft³) (21 in)
- 62.2 lbs/ft³ (0.50 ft³) (21 in)
- 352 lbs (21.61'') + 62.2 lbs/ft³
(0.66 ft³) (8 in) + 62.2 lbs/ft³ (2.16 ft³) 28 in
+ 62.2 lbs/ft³ (1.095 ft³) 7.5 in
+ 62.2 lbs/ft³ (0.122 ft³) 6 in
+ 62.2 lbs/ft³ (0.14 ft³) 8 in.

CM = (8030.75 - 3030.4 - 510.8 - 8297.48 - 376.19 - 653.1
- 7606.72 + 328.4 + 3766.8 + 510.8 + 45.53 + 69.66) lbs-in.

CM = - 7727.75 lbs-in.

Angle at which the vehicle will float is (Θ)

Θ = 345°



Θ = 345°

This would mean that the cabin would be almost completely submerged.

Therefore, assuming that 1/2 of the total volume of the cabin is occupied by water,

the volume displaced by the:

Tunnel	=	2.98 ft^3
Cabin	=	4.33 ft^3
Fuel tank & seat	=	2.19 ft^3
Cargo area	=	2.43 ft^3
Suspension	=	0.40 ft^3
Track	=	0.64 ft^3
		12.97 ft^3

The equilibrium position is:

Point of reference is 0.72'' to the right of the center of mass.

CM = 17.65'' (455 lbs) - 62.2 lbs/ft^3 (2.32 ft^3) (21'')
- 62.2 lbs/ft^3 (1.095 ft^3) (7.5 in)
- 62.2 lbs/ft^3 (2.43 ft^3) (29 in)
- 62.2 lbs/ft^3 (0.288 ft^3) (21 in)
- 62.2 lbs/ft^3 (0.50 ft^3) (21 in)
- 352 lbs (21.61'') + 62.2 lbs/ft^3
(0.66 ft^3) (8 in) + 62.2 lbs/ft^3 (4.33 ft^3) 28 in
+ 62.2 lbs/ft^3 (1.095 ft^3) 7.5 in
+ 62.2 lbs/ft^3 (0.122 ft^3) 6 in
+ 62.2 lbs/ft^3 (0.14 ft^3) 8 in.

CM = (8030.75 - 3030.4 - 510.8 - 4383.2 - 376.19 - 653.1
- 7606.72 + 328.4 + 7541.1 + 510.8 + 45.53 + 69.66) lbs-in.

CM = - 34.2 lbs-in.

This would indicate that the vehicle is at an equilibrium position at an angle of 345°.

F. Gabbianelli,
Project Engineer
12/04/84

Appendix F

SAMPLE FREIGHT COSTS TO NORTHERN COMMUNITIES

Air Freight Costs of a 200kg Shipment from Southern Centers to Northern Communities

Origin + Airline	Destination	Freight Rate $/kg	Cost for 200 kg
Montreal via Nordair & First Air	Kuujjuaq	1.98	396
	Frobisher Bay	2.36	472
	Hall Beach	2.47	494
	Nanasivik	2.50	500
	Resolute Bay	2.50	500
	Broughton Isl.	4.28	856
	Cape Dorset	4.01	802
	Clyde River	5.57	1114
	Igloolik	3.00	600
	Lake Harbour	3.10	620
	Pangnirtung	3.69	738
	Pelly Bay	3.81	762
	Pond Inlet	6.03	1206
	Povungnituk	1.73	346
	Sanikiluaq	1.73	346
	Repulse Bay	3.70	740
Montreal via Nordair& Air Inuit	Leaf Bay	2.92	584
	Payne Bay	3.42	684
	Aupaluk	3.04	608
	Koartak	4.10	820
	Wakeham Bay	4.86	972
	Deception Bay	5.68	1136
	Sugluc	6.00	1200
	George River	3.04	608
Winnipeg via NWT/AIR	Rankin Inlet	1.39	278
Winnipeg via Pacific Western & Calm Air	Churchill	1.05	210
	Baker Lake	2.30	460
	Eskimo Point	1.60	310
	Coral Harvour	2.97	594
	Repulse Bay	3.05	610
	Chesterfield In.	3.15	430
	Whale Cove	1.80	360

Edmonton via NWT/Air $ Pacific Western	Yellowknife Cambridge Bay Coppermine Holman Island Gjoa Haven Spence Bay Pelly Bay Fort Simpson Norman Wells Hay River	1.14 2.50 2.69 3.29 5.35 5.59 5.97 1.73 2.11 .98	228 500 538 658 1070 1116 1094 346 422 196
Edmonton via Kenn Borek & Pacific Western	Inuvik Aklavik Fort McPherson Paulatuk Sachs Harbour Tuktoyaktuk	2.34 2.87 3.17 4.44 3.99 3.94	468 574 634 888 798 788
Edmonton via Trans North Air	Whitehorse Dawson City Faro Juneau MacMillan Pass Mayo Ross River Old Crow Watson Lake	1.18 2.98 2.22 2.20 2.76 2.56 2.22 3.62 2.59	236 596 444 440 552 512 436 724 518

Trucking, Rail, and SeaLift Costs for a 200kg Shipment to the Arctic

Origin	Destination	Freight Rate $/ton	Cost for 200 kg
Montreal Sealift only	Grise Fiord	270	54.00
	Resolute Bay	270	54.00
	Arctic Bay	270	54.00
	Pond Inlet	270	54.00
	Clyde River	345	68.10
	Broughton Is.	345	68.10
	Igloolik	275	55.00
	Hall Beach	275	55.00
	Pelly Bay	275	55.00
	Repulse Bay	275	55.00
	Coral Harbour	275	55.00
	Pangnirtung	192	38.40
	Frobisher Bay	192	38.40
	Lake Harbour	192	38.40
	Cape Dorset	192	38.40
	Ivujivik	240	48.00
	Sugluc	240	48.00
	Wakeham Bay	240	48.00
	Koartac	240	48.00
	Port Burwell	240	48.00
	Payne Bay	240	48.00
	Leaf Bay	240	48.00
	George River	240	48.00
	Fort Chimo	240	48.00
	Povungnituk	240	48.00
	Inoucdjouac	240	48.00
	Sanikiluaq	240	48.00
Winnipeg rail to Churchill then sealift	Baker Lake	605	136.00
	Chesterfield In.	605	136.00
	Rankin Inlet	605	136.00
	Whale Cove	605	136.00
	Eskimo Point	605	136.00
	Churchill	286	65.00
Edmonton trucking/rail to Hay River then sealift	Hay River	344	78.36
	Tuktoyaktuk	517	117.65
	Sachs Harbour	574	130.67
	Paulatuk	626	142.38
	Holman Island	602	136.92
	Cambridge Bay	682	155.22
	Coppermine	652	148.36
	Spence Bay	731	166.31

Edmonton continued	Gjoa Haven	716	162.92
	Fort Smith	403	91.78
	Fort Simpson	439	99.96
	Fort Providence	374	85.22
	Fort Resolution	403	91.78
	Fort Ray	480	109.29
	Yellowknife	480	109.29
	Dawson City	403	91.78
	Whitehorse	344	78.36
	Watson Lake	448	102.00
	Faro	560	127.46